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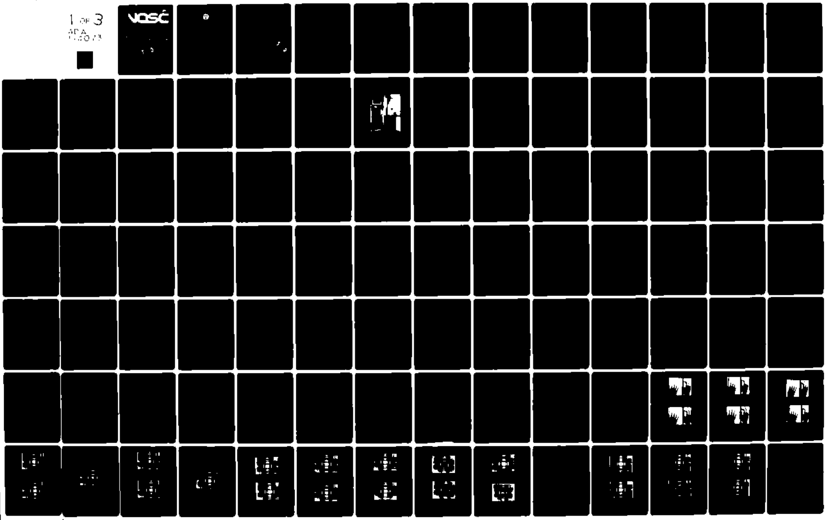

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Technical Report 691

REMOTE MEDICAL DIAGNOSIS SYSTEM (RMDS) ADVANCED DEVELOPMENT MODEL (ADM) LABORATORY TEST RESULTS

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January 1982

Prepared for
Naval Medical Research and Development Command
Code 45
Bethesda, MD

NAVAL OCEAN SYSTEMS CENTER
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NAVAL OCEAN SYSTEMS CENTER, SAN DIEGO, CA 92152

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ADMINISTRATIVE INFORMATION

This Technical Report is one in a series of reports for the Remote Medical Diagnosis System (RMDS), Program Element 6477IN, Project M0933-PN (NOSC 512-CM38), sponsored by the Naval Medical Research and Development Command, Code 45. It contains the test results of a laboratory evaluation of the RMDS Advanced Development Model (ADM) terminals. This report was prepared by the NOSC Bioengineering Branch (Code 5123) and WESTEC Services, Inc. (Contract N66001-78-C-0274). The evaluation testing described in this report was conducted during the period April 1978 to May 1979. Principal investigators were I Stevens, PD Hayes (NOSC), J West, and FW Hutzelman (WESTEC Services, Inc.), under the direction of WT Rasmussen, Head, Bioengineering Branch.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report provides laboratory experimental evaluation of video transmissions of radiographs over the Remote Medical Diagnosis System (RMDS) advanced development model terminals. The objectives of this evaluation were (1) to obtain quantitative and qualitative data on the functional parameters of the RMDS ADM terminals and components; (2) to define design risks associated with the current approach to RMDS implementation, and (3) to provide baseline data to support follow-on procurement of RMDS engineering development model (EDM) terminals.

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OBJECTIVE

Obtain quantitative and qualitative data on the functional parameters of the RMDS ADM terminals and components, define design risks associated with the current approach to RMDS implementation, and provide baseline data to support follow-on procurement of RMDS Engineering Development Model (EDM) terminals.

RESULTS

1. In general, the RMDS ADM terminals operated satisfactorily and within specification during laboratory testing at NOSC. A summary of general systems measurements is given in tables 49 and 50, which list the technical performance parameters of various elements and operational modes of the ADM terminals.
2. Electrocardiograph signal transmission was of sufficient quality for diagnostic purposes.
3. A noticeable decrease was observed in the quality of stethoscopic heart sounds via analog transmission; this decrease is not felt to be tolerable for diagnostic purposes.
4. The quality of video image transmission was good, with only slight variations between analog, digital, coarse, and fine modes of operation. Better quality was obtained for the digital and fine modes versus analog and coarse modes of operation, but all video images were of sufficient quality for diagnostic purposes in most general cases.
5. Some system components, such as the audio tape recorder and X-ray viewbox, did not provide sufficient quality; and some internal electronic circuits caused signal interference.

RECOMMENDATIONS

For the procurement of future RMDS Engineering Development Models (EDMs):

1. Consider only digital transmission for video imagery.
2. Use a digital transmission mode for the stethoscopic heart/lung sounds.
3. Design the system for a minimum video resolution of 525 lines by 256 pixels, with 6 bits per pixel (525 x 256 x 6), and a preferred resolution for more detailed radiographs of 525 x 512 x 8.
4. Incorporate no audio tape recorder.
5. Provide a digital storage capability, compatible with video resolution (up to 525 x 512 x 8), ECG, and stethoscope requirements.
6. Incorporate a more uniform light source for use of video images, specifically in the lightbox for radiographs.
7. Shield the EDM terminals or employ other design changes to reduce their susceptibility to rf noise interference.
8. Design the EDM terminals to eliminate electronic interference from internal circuits. Design the system with all circuits specified at a noise level at least 10 dB below the random noise level.

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TABLES (Continued)

TABLES (Continued)

TABLES (Continued)

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

SECTION 1

INTRODUCTION

1.1 PURPOSE

This report contains the test results of a laboratory evaluation of the Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) terminals, conducted between April 1978 and May 1979. An initial period of testing was conducted between April and September of 1978. As a result of the initial testing, further testing was recommended to reevaluate various aspects of the RMDS ADM terminals. The retesting was conducted between March and May of 1979.

The objectives of the laboratory tests were to obtain quantitative and qualitative data on the functional parameters of the RMDS ADM terminals and components, define design risks associated with the current approach to the RMDS implementation, and provide baseline data to support follow-on procurement of RMDS Engineering Development Model (EDM) terminals. The raw data obtained during the laboratory evaluation have been reduced and are presented in either of three forms: tabular, graphic, or photographic. The test results are discussed, conclusions are drawn concerning the RMDS performance, and recommendations are presented for future RMDS testing and design. The test plan and guidelines for this evaluation are contained in NOSC TD 395 (ref 1).

1.2 BACKGROUND

The mission of the RMDS is to improve medical diagnosis at remote sites. This is accomplished by transmitting medical data and diagnostic information between remote ship or shore sites and full-capability medical centers. The RMDS will enable the medical personnel at a remote site to contact a physician at a diagnostic center (ashore or shipboard) and transmit a visual and auditory presentation of the medical data needed for diagnosis, such as patient history, laboratory tests, ECG tracings, X-ray images, images of a patient injury, heart-lung sounds, and verbal descriptions. By return link, the physician will be able to send diagnosis and treatment information. The communication requirements are satisfied by any two-way, voice-grade, narrowband communication channel such as telephone line, hf or uhf radio, or a satellite link.

Shipboard feasibility tests of an early RMDS prototype were completed during FY 75/76. This testing showed that the concept was feasible and that equipment could be developed to meet the requirements by using available technology (ref 2). Because of various constraints (eg, narrow bandwidth, short transmission times, etc), the resolution and gray scale to be achieved in transmitting and displaying radiographic data

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1. NOSC TD 395, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Test Plan, WT Rasmussen, I Stevens (NOSC), and J West (WESTEC Services, Inc.), December 1980.

2. NOSC TR 659, Feasibility Tests of the Remote Medical Diagnosis System, WT Rasmussen, I Stevens (NOSC), and JA Kuhlman (WESTEC Services, Inc.), January 1981.

should be kept to a minimum to meet essential requirements. In order to derive minimum resolution data, a radiology study with eight radiologists was conducted in FY 77, using a special digital closed-circuit television system to simulate the RMDS equipment (ref 3).

As a result of those feasibility and radiology tests, NOSC undertook a development project to produce two Advanced Development Model RMDS terminals; the ADMs were procured in September 1977. The RMDS ADM terminals were tested for technical performance at NOSC from September 1977 to September 1979. During this period, the ADMs were tested at sea, with one terminal aboard USS ENTERPRISE (CVN 65) from 28 February to 5 March 1978; at-sea test results are documented in NOSC TR 690 (ref 4). Image fidelity evaluation testing of radiograph transmission via the ADMs was performed during the period October 1978 to April 1979; those test results are documented in NOSC TR 683 (ref 5).

1.3 SYSTEM DESCRIPTION

The system as a whole consists essentially of the RMDS terminals, the existing voice-grade communication links used to interconnect the terminals, and user personnel. Contained in the terminals is all the hardware that is unique to the system: TV camera, TV monitor, X-ray light box, electronic stethoscope, ECG monitor, audio tape recorder, audio handsets, and the electronics package, consisting of signal modulator, demodulator, and modems. Figure 1 illustrates the RMDS Advanced Development Model (ADM).

Two RMDS terminals have been designed: one for shipboard use; the other for shore use. The two terminals are essentially identical except for the capability to link to the basic interunit communication channel. The shore unit uses a dial telephone for establishing landline communications to rf communication centers. The shipboard unit also contains an intercom unit to interface with radio central. The shipboard terminal interfaces with Navy communications equipment via a C1138B/UR. Both terminals are functionally capable of sending and receiving ECG traces, stethoscope sounds, and radiographic and patient images. In addition, each terminal provides a capability for voice communication with another RMDS terminal over the data channel (on a shared channel basis) or an auxiliary channel. The RMDS terminals themselves do not incorporate any rf communications equipment; they rely on equipment available on

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3. NOSC TR 150, Resolution Requirements for Slow-Scan Television Transmission of X-rays, WT Rasmussen (NOSC), RL Crepeau (WESTEC Services, Inc.) and FH Gerber (NRMC San Diego), 19 September 1977.

4. NOSC TR 690, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) At-Sea Test Results, WT Rasmussen, I Stevens, PD Hayes (NOSC), and J West (WESTEC Services, Inc.), January 1982.

5. NOSC TR 683, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Radiology Performance Test Results, WT Rasmussen, PD Hayes, I Stevens (NOSC), FH Gerber (NRMC San Diego), JA Kuhlman, and FW Hutzelman (WESTEC Services, Inc.), January 1982.

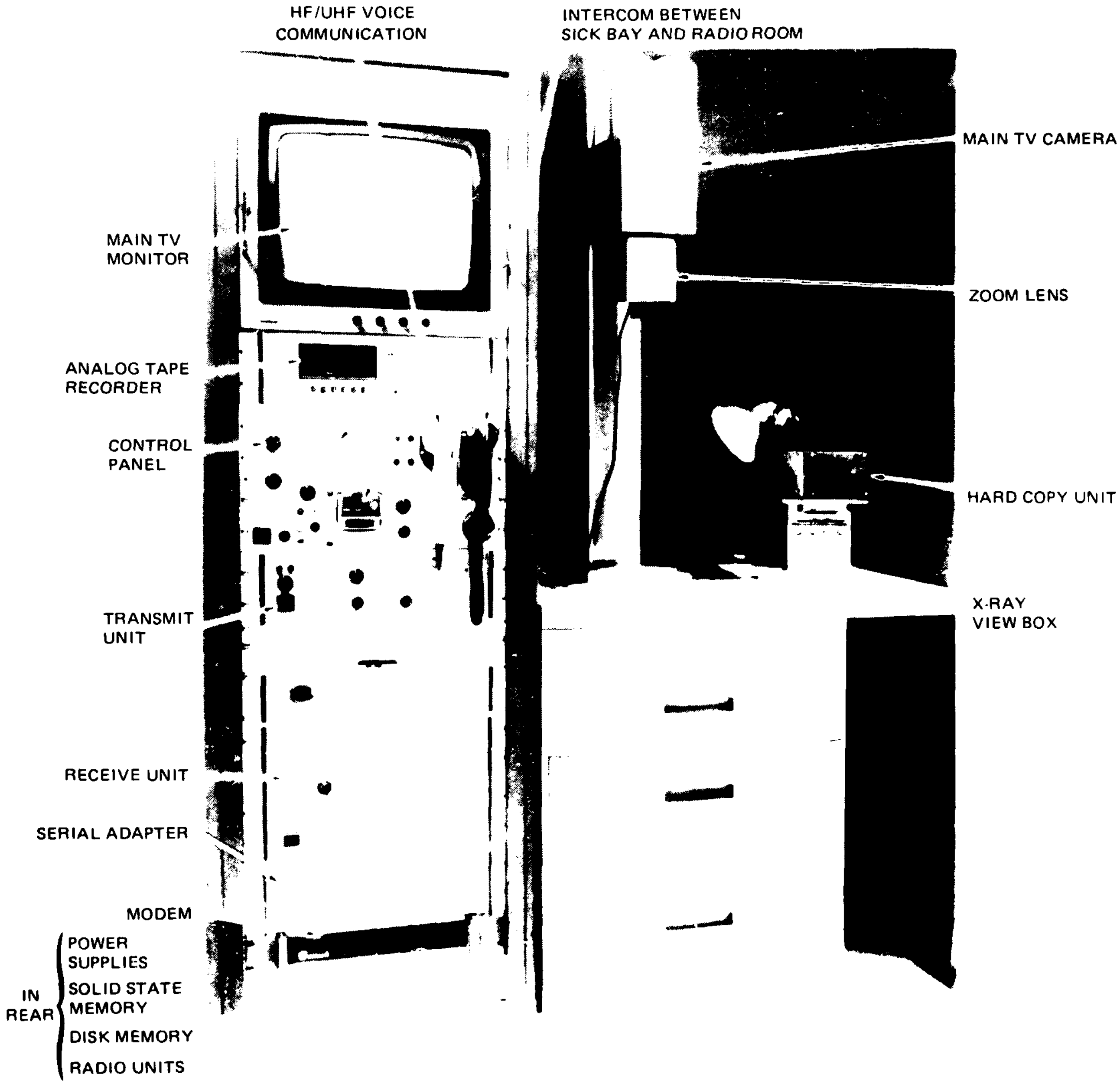

Figure 1. Advanced Development Model (ADM) RMDS terminal and related components.

shipboard or ashore. The function and operation of the ADM terminal are described in NOSC TD 397 (ref 6).

The RMDS terminal consists of the following principal components, as depicted in figure 1:

- Main television camera (KGM Model 113T) with a Canon Model V6X16R(DC) zoom lens and supporting stand
- X-ray viewbox
- Main TV monitor* (17" Electrohome, Model EVM 171OR)
- Audio tape recorder for recording transmission line signals (Sanyo Model RD4553)
- Control panel, including transmit/receive data selection, camera controls, system controls, panel microphone and speaker controls, external and internal voice communication controls, and voice communication handsets
- Video transmit unit, including video disc recorder (Modified CVI Model 260B)
- Video receive unit, including solid-state memory for up to 525 lines x 256 picture elements at 6 bits per picture element (Modified CVI Model 275)
- Hard-copy unit, consisting of 5" auxiliary TV monitor and Polaroid camera
- ECG strip chart recorder (MFE Corp. Model M-21) (not shown)
- Serial adapter
- Modem (Model ICC 24) 2400 bps
- Two radio control units (C-1138B/UR)
- Remote TV camera, including monitor, tripod, zoom lens, 50 feet of cable, and padded carrying case (not shown)
- Stethoscope pickup unit (not shown)
- ECG machine (Model HP 1500B) (not shown)
- Mounting racks and miscellaneous hardware

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6. NOSC TD 397, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Operator's Manual, WT Rasmussen, PD Hayes, I Stevens, EW Davenport (NOSC), and JA Kuhlman (WESTEC Services, Inc.), July 1981.

*The shore RMDS terminal may have a second TV monitor for simultaneous display of two images.

SECTION 2

TEST DESCRIPTION

The RMDS electrocardiogram (ECG), stethoscope, and video image transfer modes were tested, both quantitatively and qualitatively, using various communication links, ie, back-to-back, local telephone lines, long distance telephone lines, hf and uhf/satellite. The RMDS transmitting and receiving terminals were located in adjacent rooms of the NOSC bioengineering laboratory, except during uhf/satellite testing when they were placed side-by-side in the NOSC satellite communication building.

The qualitative tests were designed to assess the operational utility of the RMDS under laboratory conditions for the three modes of operation, ie, ECG, stethoscope, and video image transfer. After the appropriate communication link was established between the transmitting and receiving terminals, either simulated electrocardiograms, stethoscopic sounds, or video images (including radiographs and resolution test patterns) were transmitted between RMDS terminals. Subjective comparison and analysis were made of the quality of data received per communication link and transmission mode (analog versus digital, coarse versus fine resolution). The quantitative tests for ECG, stethoscope, and video information transfer were performed to document technical design issues under laboratory conditions. Comparison and analysis were performed on the quantitative data obtained during testing for the various communication links and transmission modes.

Detailed information on test conditions and methods is given in NOSC TD 395 (ref 1). The data obtained from the qualitative and quantitative testing were recorded on data sheets, as contained in NOSC TD 395, vol 3. Tables 1 and 2 summarize the qualitative and quantitative tests and test conditions performed during the laboratory test and retesting periods, respectively. A detailed description of the laboratory retesting is provided within this report where differences in testing procedures existed.

Testing was conducted with the components configured as they had been designed to be operated, using only the adjustments and controls available within the system. No special modifications or equipment additions were made to the RMDS terminals for the purpose of improving system performance during testing. All equipment for the testing of the RMDS terminals was provided by NOSC, San Diego. This included all components (TV cameras, monitors, ECG units, etc), test equipment, and test materials. The RMDS equipment used in this testing program was procured specifically for these tests. Maintenance and operation of the RMDS terminals were conducted by NOSC personnel.

Test Title	Communication Link*	Variables
• ECG Mode		
- Qualitative	B/B, LT, LDT	Simulated signal; tape recorder playback
- Harmonic Distortion	B/B, LT, LDT	0.3 V RMS 25 Hz signal
- Linearity	B/B	-2.5 V to +2.5 V DC levels
- Noise Level	B/B, LT, LDT	
• Stethoscope Mode		
- Qualitative	LT, LDT	Recorded heart sounds
- Frequency Response	B/B	0.5 V, 0.75 V, 1.00 V, and 1.25 V p-p input
- Phase Response	B/B, LDT	1.25 V p-p input
- Harmonic Distortion	B/B, LT, LDT	0.3 V RMS 500 Hz signal
- Noise Level	B/B, LT, LDT	
• Video Mode		
- Qualitative	B/B, LT, hf, uhf/sat	Main and remote camera; analog and digital; fine and coarse resolution
- Viewbox Lighting Uniformity		

*B/B - Back-to-Back
LT - Local Telephone Line
LDT - Long Distance Telephone Line
hf - High Frequency
uhf/sat - Ultrahigh Frequency/Satellite

Table 1. Index of RMDS original laboratory testing.

Test Title	Communication Link*	Variables
- Horizontal Resolution	B/B, LT, LDT	TV camera/lens system (center and corner field; pattern-to-lens distance; 1.0 optical density filter); frame freeze (center and corner field); analog and digital (center and corner field; camera and disc recorder image)
- Flatness of Field		Field of view (7½" x 10" and maximum); 1.0 optical density filter
- Geometric Linearity		TV camera
- Signal-to-Noise Level	B/B, LT, LDT	TV camera/lens system; frame freeze; analog and digital (camera and disc recorder image)
- Equalization	B/B, LT, LDT	TV camera/lens system; frame freeze; analog and digital (camera and disc recorder image)
- Video Recorder Time Base Stability		Frame freeze

*B/B - Back-to-Back
LT - Local Telephone Line
LDT - Long Distance Telephone Lines
hf - High Frequency
uhf/sat - Ultrahigh Frequency/Satellite

Table 1. Index of RMDS original laboratory testing (cont).

Test Title	Communication Link*	Variables
- Video Transmission Time	B/B	Analog and digital (2400, 4800, and 9600 bps); coarse and fine resolution
- Gray Scale Response	B/B, LT, LDT	TV camera/lens system; frame freeze; analog and digital (camera and disc recorder image)
- Tape Recorder Performance	LT	Tape recorder

*B/B - Back-to-Back
LT - Local Telephone Line
LDT - Long Distance Telephone Lines
hf - High Frequency
uhf/sat - Ultrahigh Frequency/Satellite

Table 1. Index of RMDS original laboratory testing (cont).

Test Title	Communication Link*	Variables
• ECG Mode		
- Qualitative	B/B, LDT	Simulated signal; tape recorder playback
- Harmonic Distortion	B/B	Tape recorder playback
- Linearity	B/B	-2.5 V to +2.5 V DC levels
- Noise Level	B/B, LT, LDT	Tape recorder playback
- Receiver Sensitivity	B/B	Signal attenuation; noise addition
• Stethoscope Mode		
- Noise Level	B/B, LT, LDT	Tape recorder playback
• Video Mode		
- Horizontal Resolution	B/B	TV camera/lens system; frame freeze; analog and digital
- Vertical Resolution	B/B, LT, LDT	TV camera/lens system; frame freeze; analog and digital
- Signal-to-Noise Level	B/B, LT, LDT	TV camera/lens system; frame freeze; analog and digital
- Gray Scale	B/B, LT, LDT	TV camera/lens system; frame freeze; analog and digital

*B/B - Back-to-Back
LT - Local Telephone Line
LDT - Long Distance Telephone Line

Table 2. Index of RMDS laboratory retesting.

SECTION 3

SIMULATED ELECTROCARDIOGRAM (ECG) TESTS

3.1 QUALITATIVE TESTING

Original Testing

Testing was conducted in which the RMDS terminals transmitted and received simulated ECG signals. Figure 2 shows the test setup used. A Parke-Davis 3175 Generator/Calibrator was used to drive a Hewlett-Packard (HP-1500B) ECG recorder at the transmitting unit. The auxiliary output of the ECG recorder was used as the ECG input to the transmitting terminal. Transmission was conducted via back-to-back, local telephone line, and long distance telephone line communication links. The ECG output of the receiving unit was input to a second HP 1500B ECG.

Samples of the results of these tests, in the form of ECG strips, are shown in figures 3 through 8. Figures 3 through 5 show the calibration pulses used at the beginning of each test run, and figures 6 through 8 are signal traces of simulated ECG transmissions and receptions corresponding to the V unipolar ECG lead configuration. The equipment operated as expected, except that the playback tape recorder failed after the back-to-back terminal configuration had been completed; it was inoperable for the remainder of the first period available for laboratory testing. The ECG data were transferred relatively faithfully in terms of amplitude and frequency response, although a general attenuation of the signal at the receiving terminal was observed. The attenuation manifested itself as a 10 to 28% decrease in height of the received ECG signal peaks, as indicated by points A through C of figures 6, 7, and 8. A greater amount of attenuation was observed in the sharp negative peaks (point B of figures 6, 7, and 8). The increase in attenuation observed in the large negative-moving pulses (with respect to baseline voltage) would have its greatest effect on the ventricular depolarization waveforms (QRS) when using V, aVL, and aVR ECG lead configurations. These attenuations reflect the cumulative frequency response (attenuation) of the RMDS and ECG terminal amplifiers at the higher frequencies. Thus, the narrow spikes of figures 6 to 8 represent frequencies of greater than 13 Hz. Attenuation of the received peak was also observed during earlier testing of the RMDS terminals (ref 7). Three possible areas were identified as sources of this attenuation 1) RMDS terminals, 2) communication links, and 3) ECG strip chart recorders. Further testing was performed to isolate the cause of this attenuation; the results of this testing are provided in Section 3.5 of this report.

The tape recorded playback of the back-to-back terminal configuration was very similar in amplitude and frequency response to the initial signal received, and it showed similar attenuation. The most noticeable effect of the playback mode was the noise observed (see figures 3c and 6c). The noise ranged from 25 to 37 Hz at 0.03 to 0.04 volt, respectively, and had the appearance of wow and flutter.

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7. NOSC TN 668, Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) Test and Evaluation Summary Report, WT Rasmussen and I Stevens (NOSC), April 1979. NOSC TNs are informal documents intended chiefly for internal use.

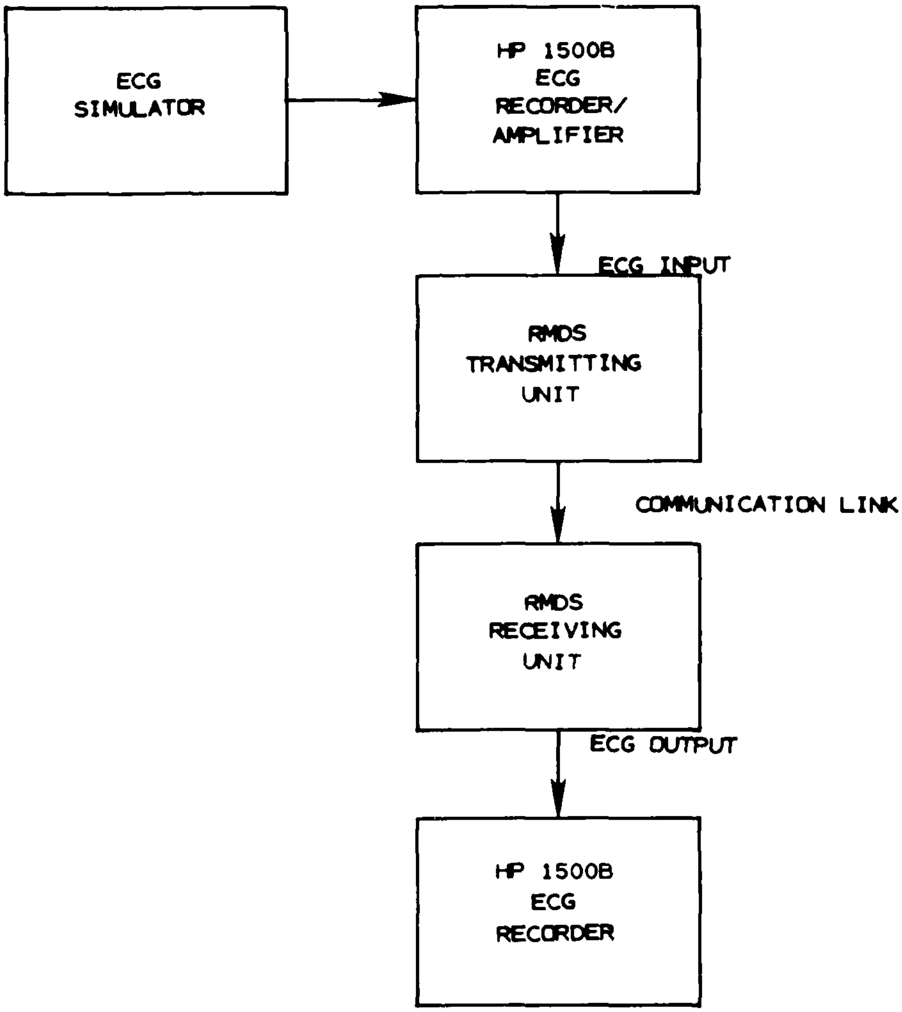
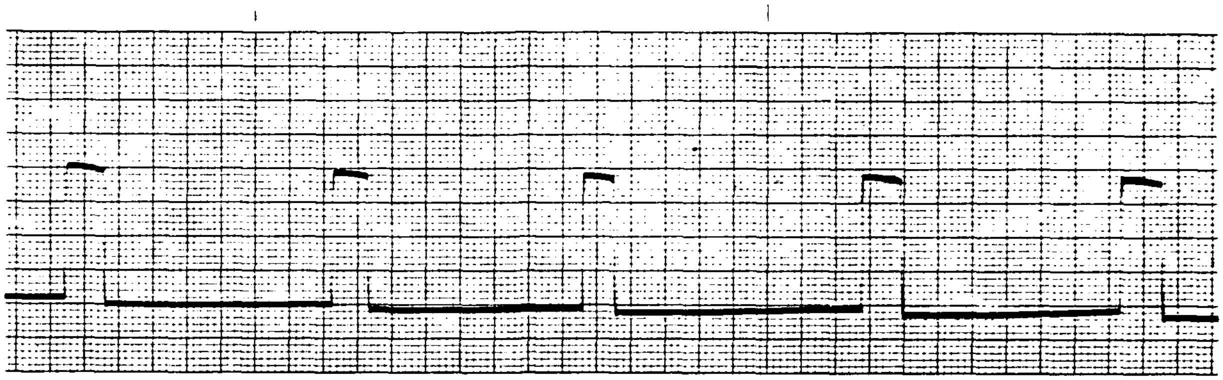
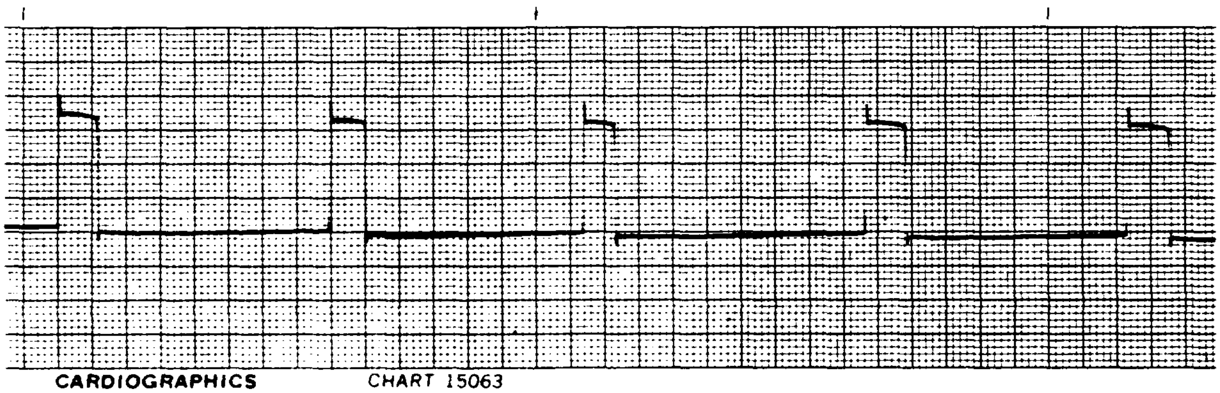


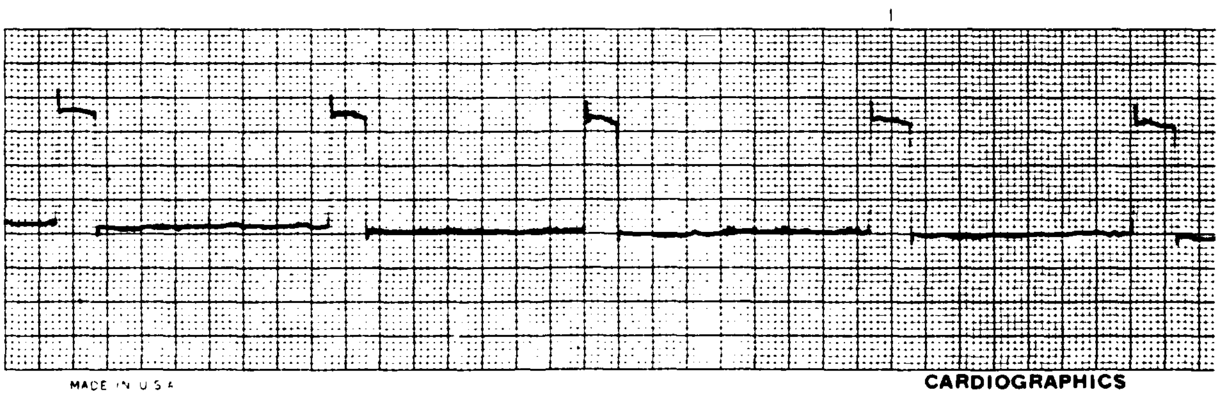
Figure 2. Simulated electrocardiograph (ECG) transmission/reception test setup.



(a) Transmitted calibration pulse

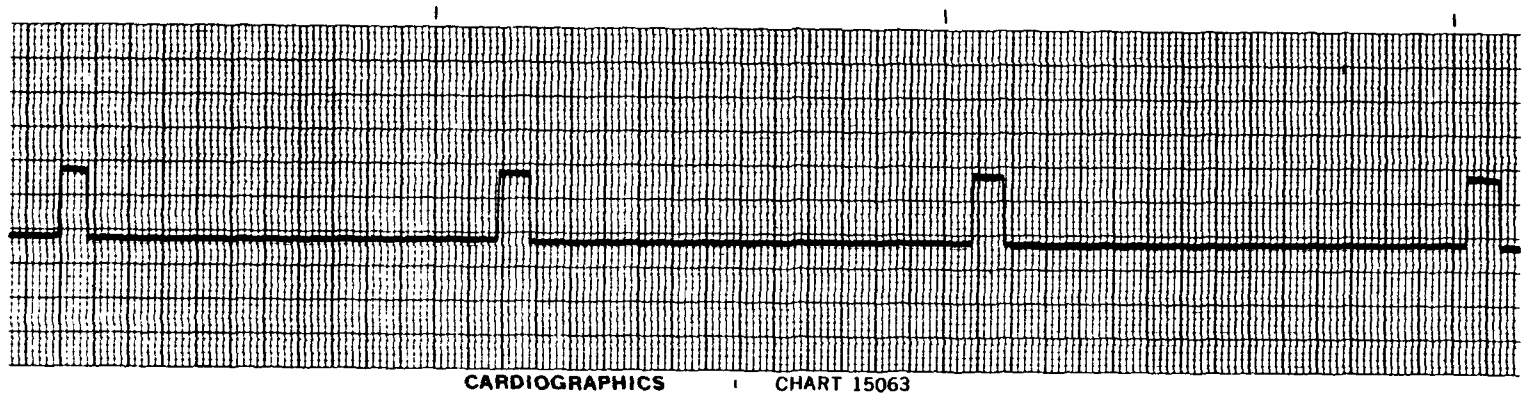


(b) Received calibration pulse

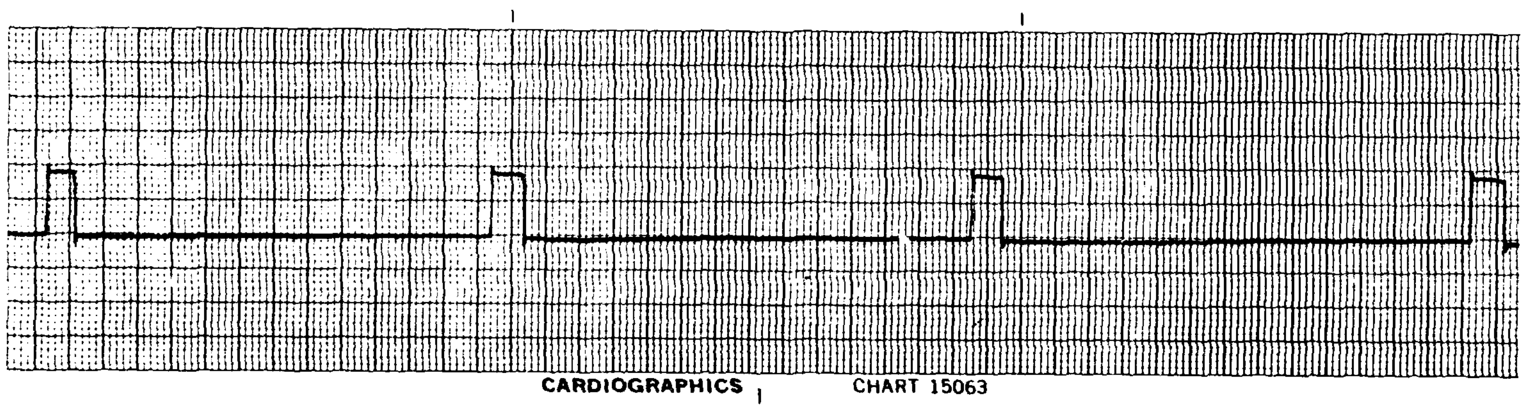


(c) Playback of magnetic recording received calibration pulse

Figure 3. Traces of calibration pulse for simulated ECG transmission/reception, back-to-back communication link.

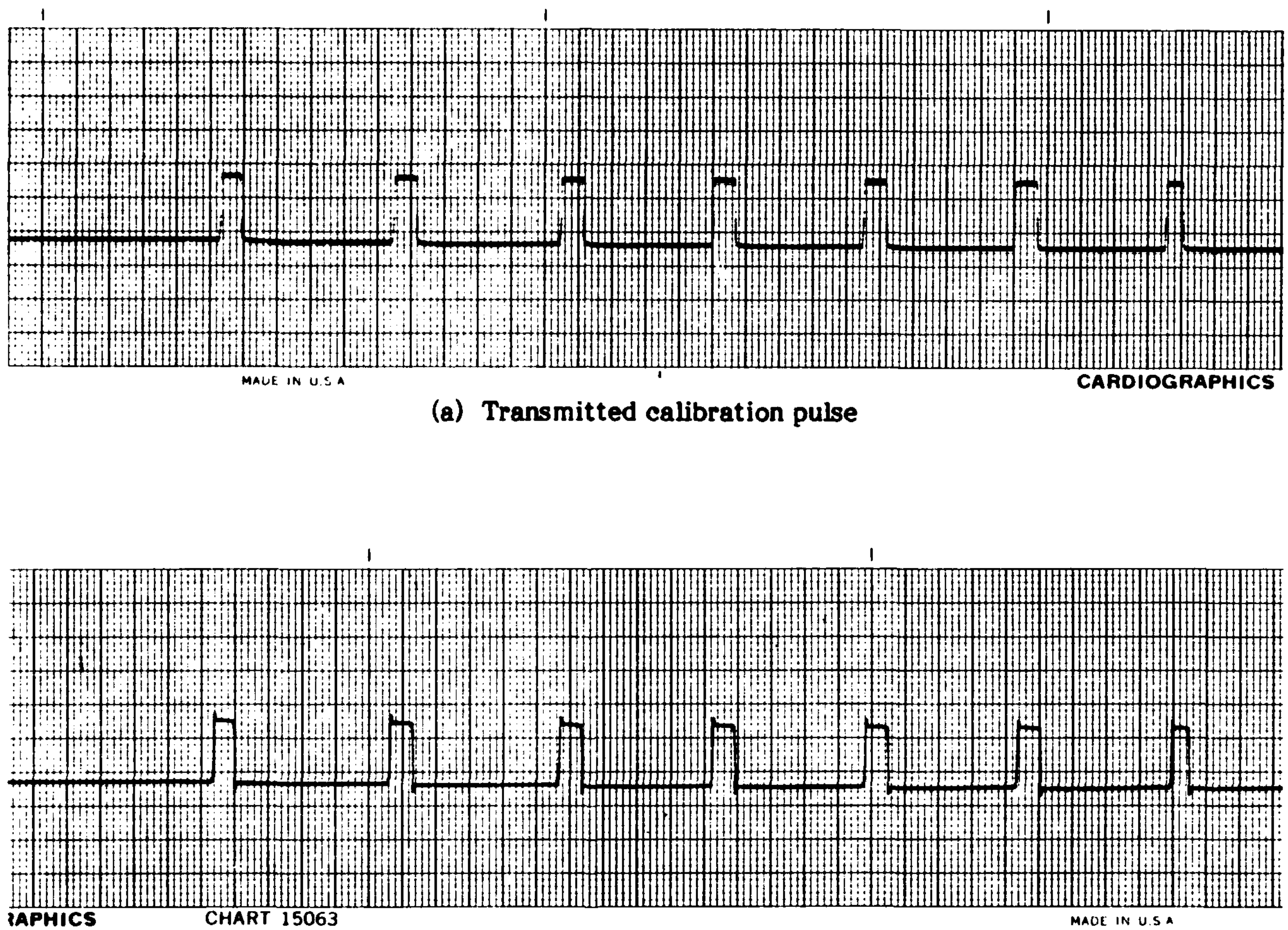


(a) Transmitted calibration pulse



(b) Received calibration pulse

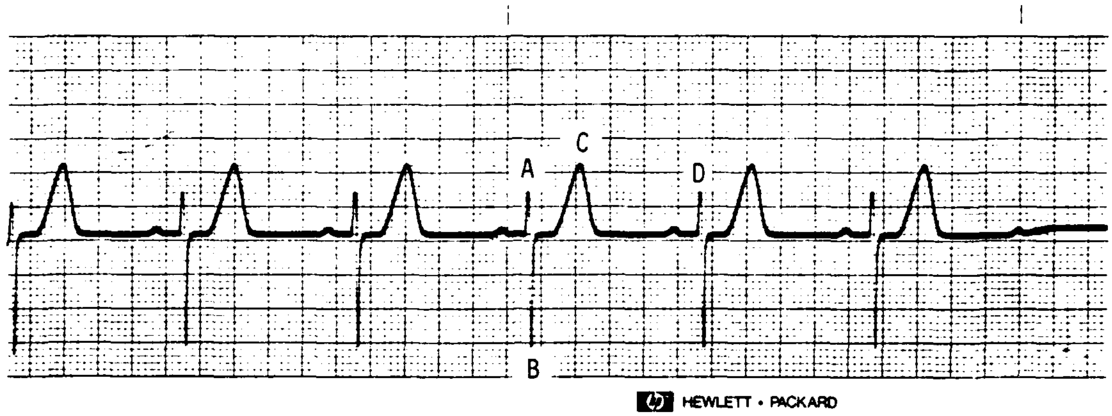
Figure 4. Traces of calibration pulse for simulated ECG transmission/reception, local telephone line communication link.



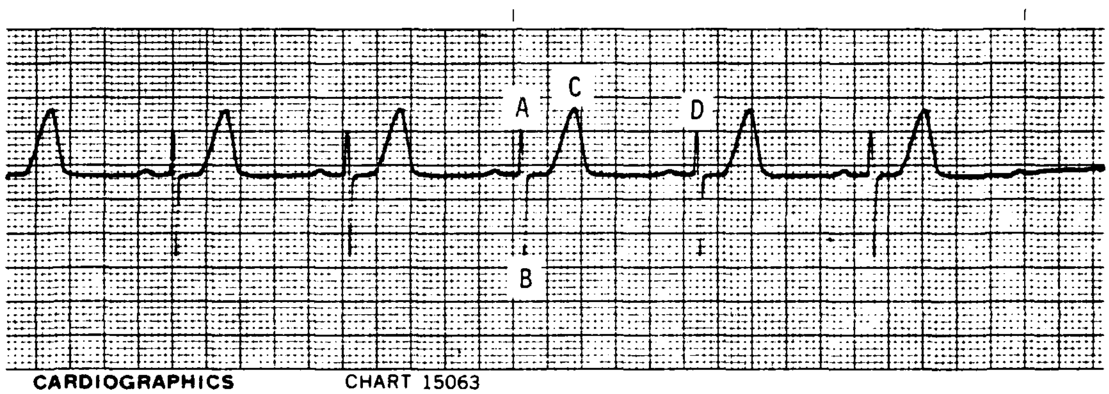
(a) Transmitted calibration pulse

(b) Received calibration pulse

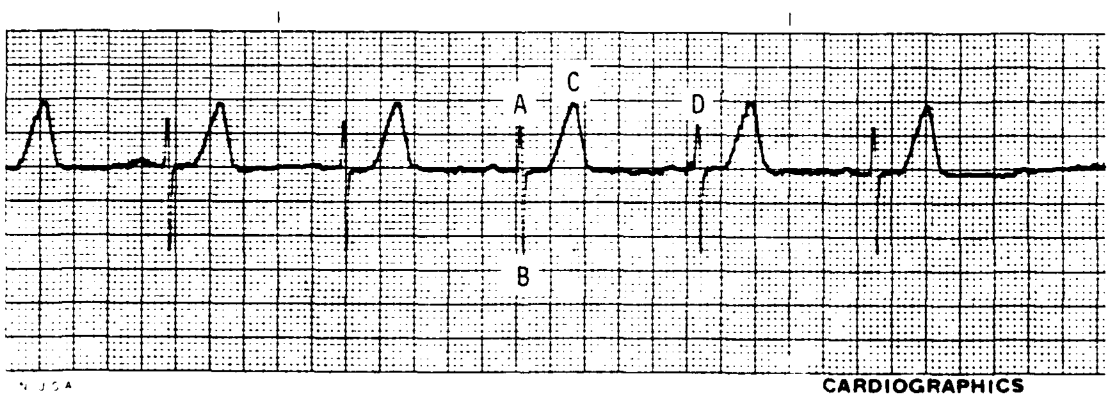
Figure 5. Traces of calibration pulse for simulated ECG transmission/reception, long distance telephone line communication link.



(a) Transmitted ECG signal

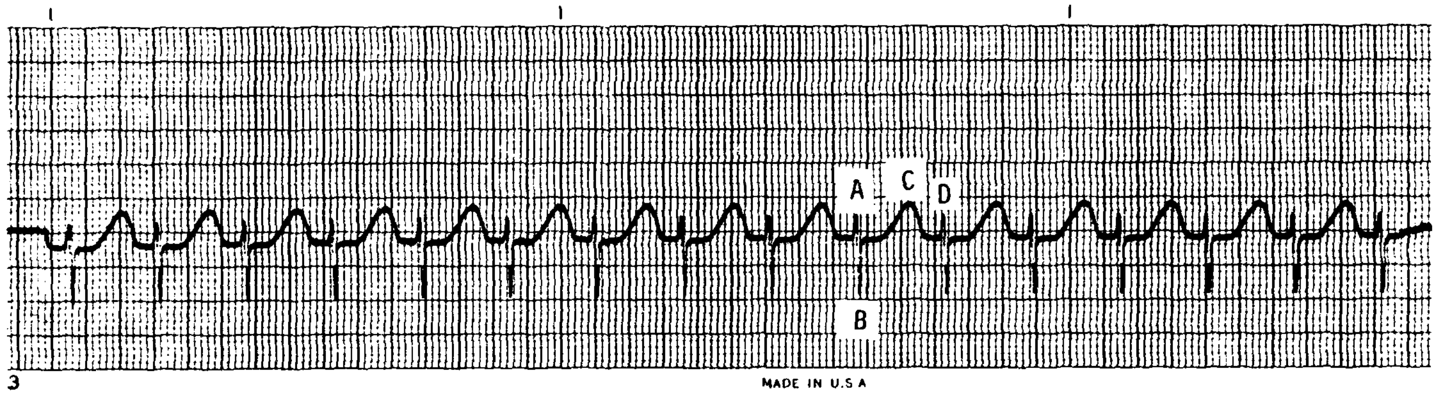


(b) Received ECG signal

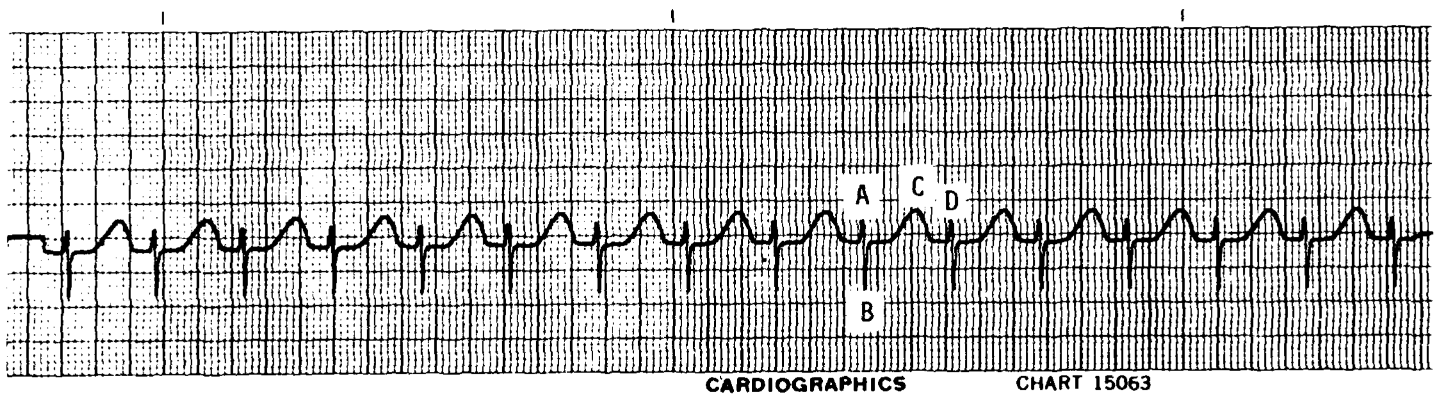


(c) Playback of magnetic recording received ECG signal

Figure 6. Signal traces for simulated ECG transmission/ reception, back-to-back communication link.

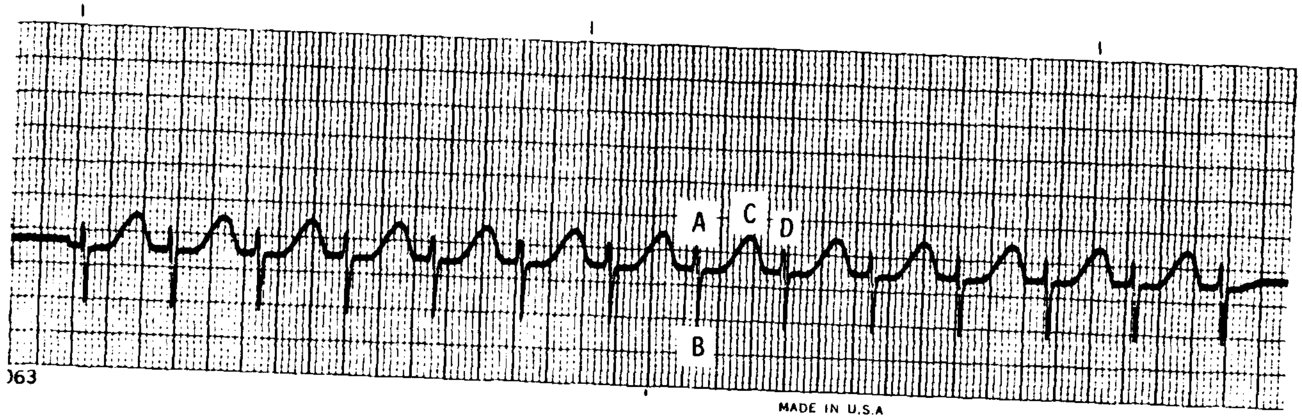


(a) Transmitted ECG signal

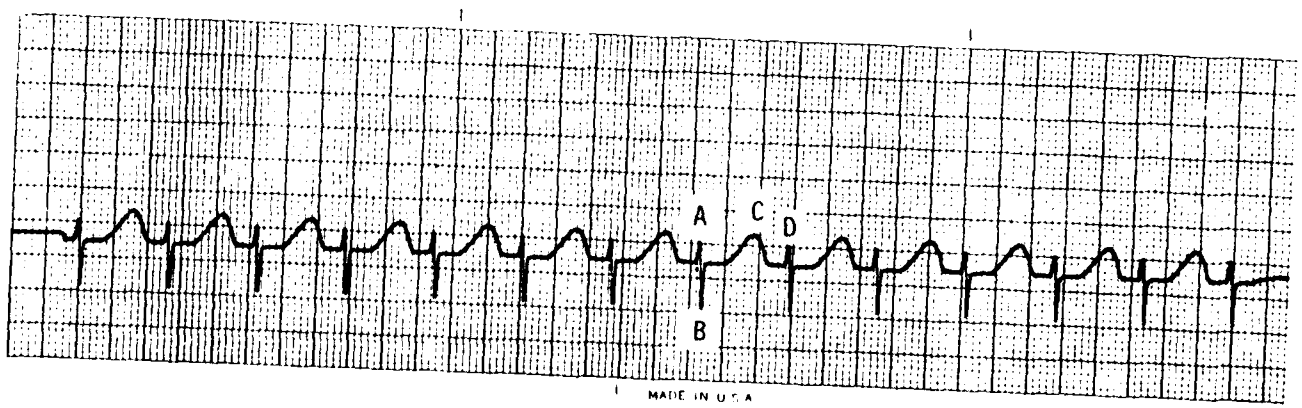


(b) Received ECG signal

Figure 7. Signal traces for simulated ECG transmission/ reception, local telephone line communication link.



(a) Transmitted ECG signal



(b) Received ECG signal

Figure 8. Signal traces for simulated ECG transmission/reception, long distance telephone line communication link.

The interval between pulses, ie, the distance between points A and D of figures 6, 7, and 8, increased by approximately 1.5% for the received ECG signal and 2.7% for the tape recorder playback. The increase was proportional for all elements of the ECG waveform, ie, PR interval, QRS duration, QT interval, and ST interval, as seen in figures 6, 7, and 8. The cause of this increase was probably the difference in strip chart drive speeds between the transmitter and receiver ECG strip chart recorders, since the increase was proportional for all elements of the ECG waveform.

Overshoot was observed on the calibration pulse used at the start of each run (see figures 3c, 4b, and 5b). It ranged from 9% to 15% depending on the height of the calibration pulse. This overshoot accounts for the increased attenuation observed in the low frequency pulse (point C of figures 6, 7, and 8) as compared to higher frequency pulses (point A of figures 6, 7, and 8).

Laboratory Retesting

Testing was conducted to determine the quality of live and tape recorder playback ECG signal transmissions. The test setup for retesting of ECG quality was similar to the original test setup (figure 2). The only difference was the use of the ECG strip chart recorder within the RMDS receiving terminal (MFE Corp. Model M-21) to record the transmitted signals. A comparison of ECG quality for tape recorder playback was performed for the variables listed below:

- Recording media (cassette tape)
- Tape recording device
- Communication link

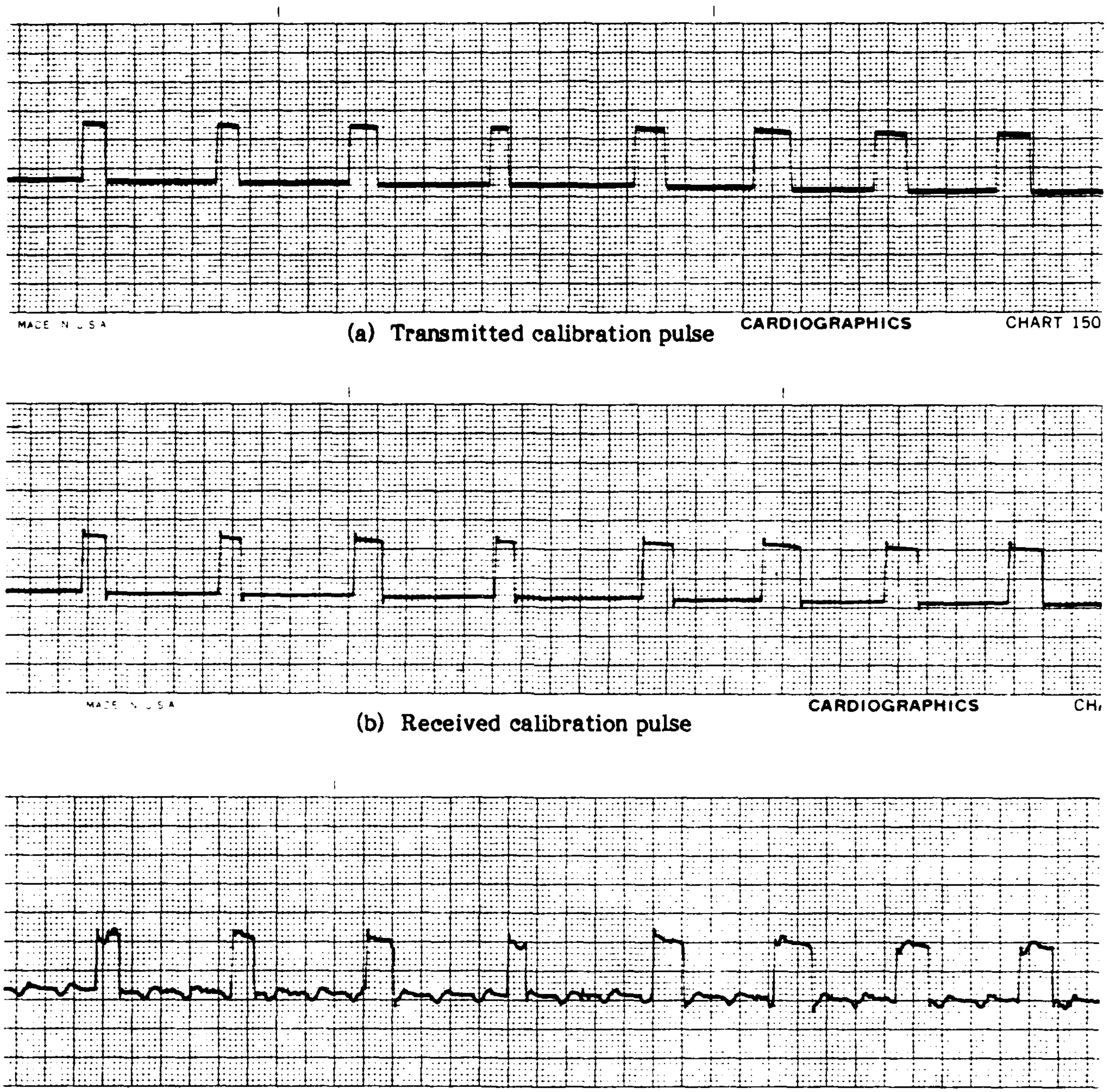
Three recording media were used during testing:

- Scotch AVC-60
- SD-C60-TDK
- Automatic ECG Tape Cassettes (Marquette Electronic, Inc.)

The audio tape records used in retesting were the Sanyo Model RD 4553 (incorporated within the RMDS receiving terminal) and a Panasonic Model RS-275-US. The input/output lines of the Panasonic tape recorder were connected to the receiving unit in the same manner as the Sanyo tape recorder. Transmission between RMDS terminals was via back-to-back and long distance telephone line communication links.

Samples of the results of these tests, in the form of ECG strips, are shown in figures 9 through 20. Figures 9 through 14 show the calibration pulse used at the beginning of each run, and figures 15 through 20 are signal traces of simulated ECG transmissions and receptions corresponding to the V unipolar ECG lead configuration.

Received ECG data were transferred relatively faithfully in terms of amplitude and frequency response. As in the original laboratory testing, a general attenuation of the signal at the receiving unit and overshoot on the calibration pulses were observed. The quality of the tape recorded playback was poor, with noticeable

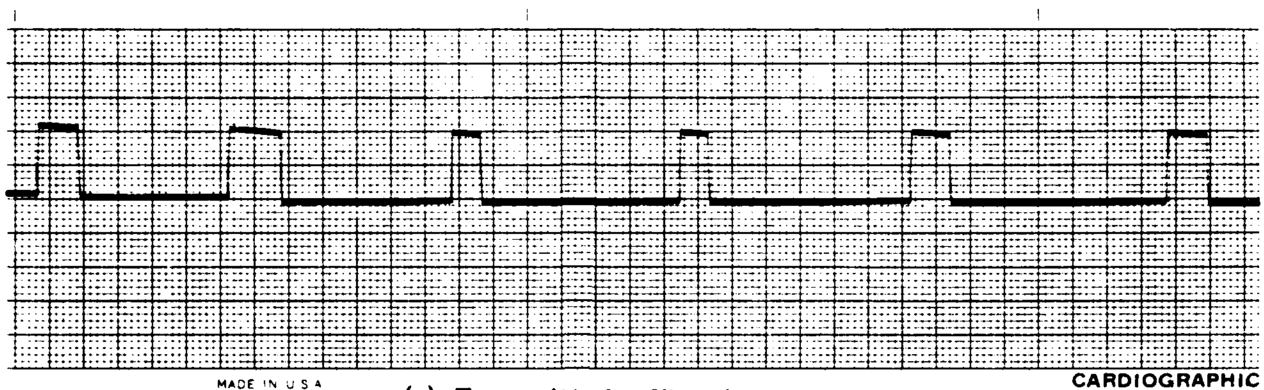


(a) Transmitted calibration pulse

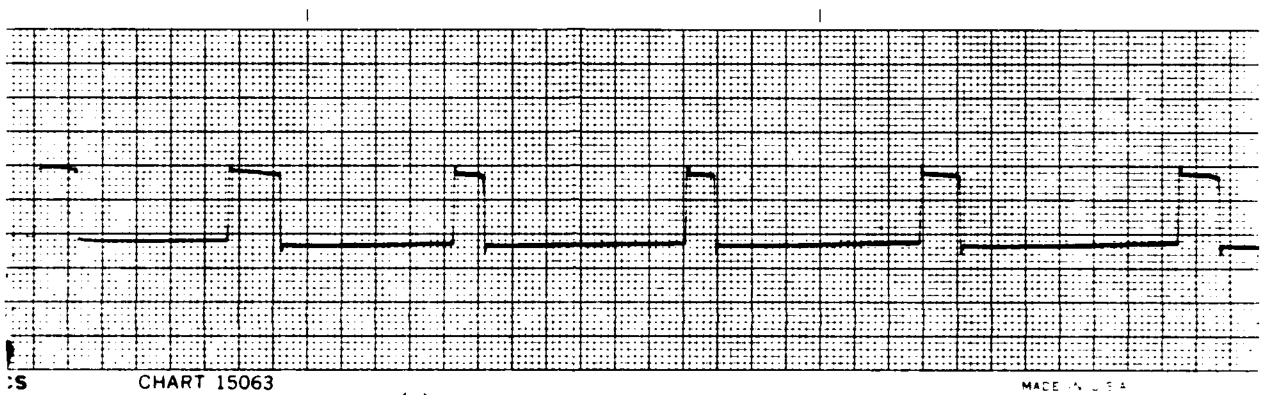
(b) Received calibration pulse

(c) Playback of magnetic recording received calibration pulse

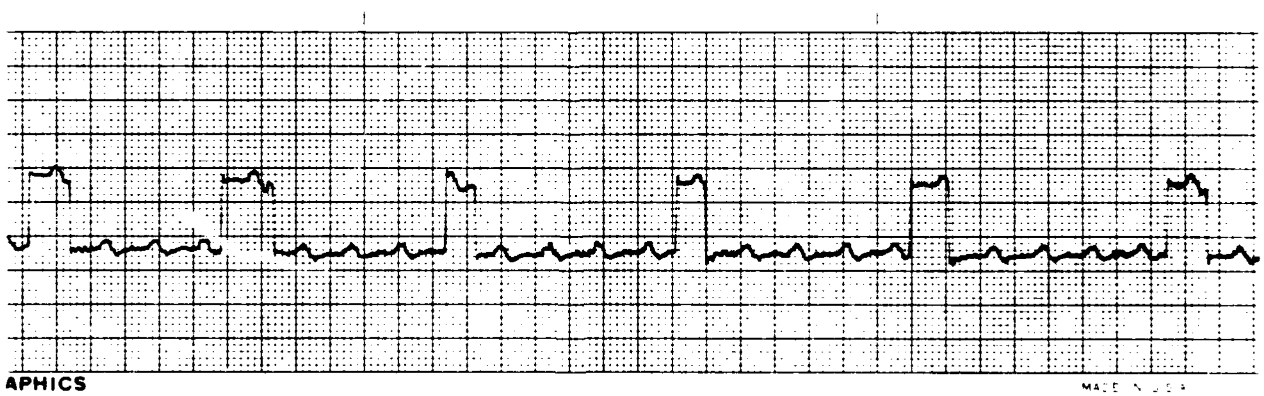
Figure 9. Traces of calibration pulse for simulated ECG transmission/reception, Scotch tape, Sanyo recorder, back-to-back.



(a) Transmitted calibration pulse

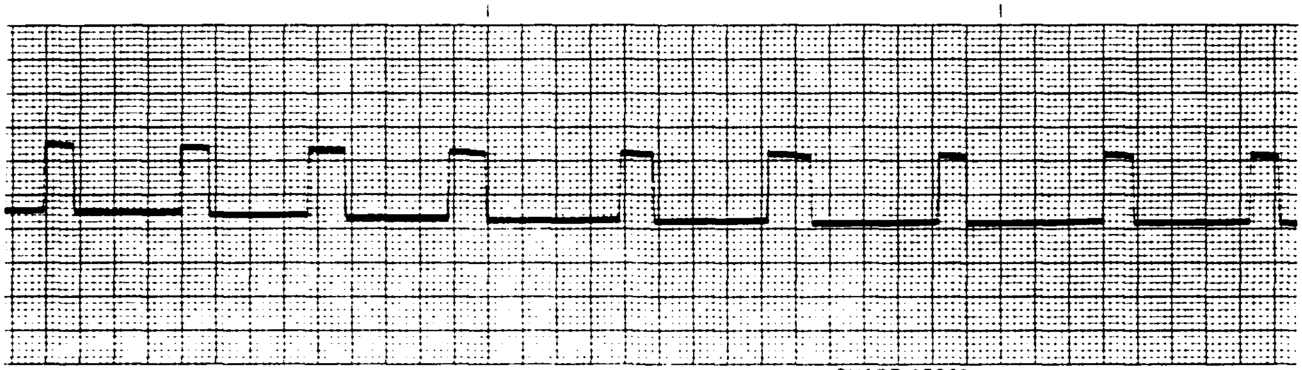


(b) Received calibration pulse

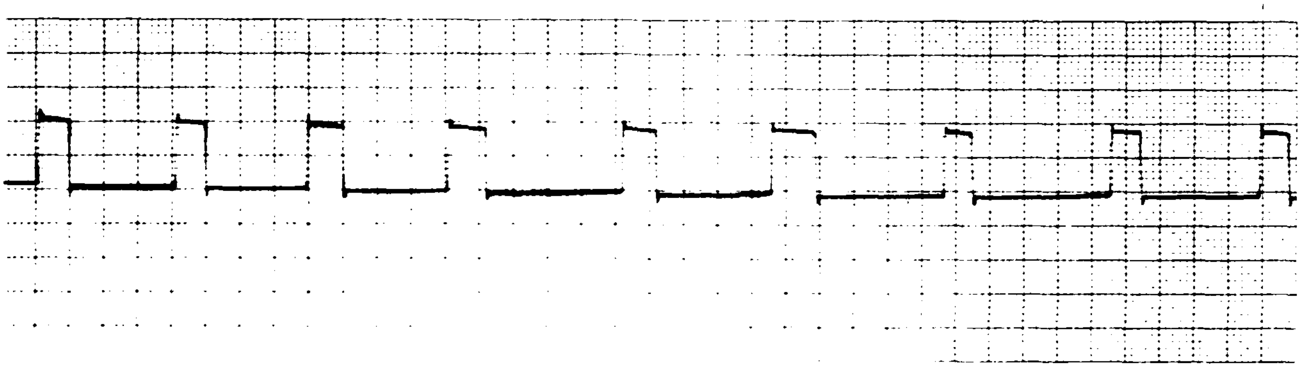


(c) Playback of magnetic recording received calibration pulse

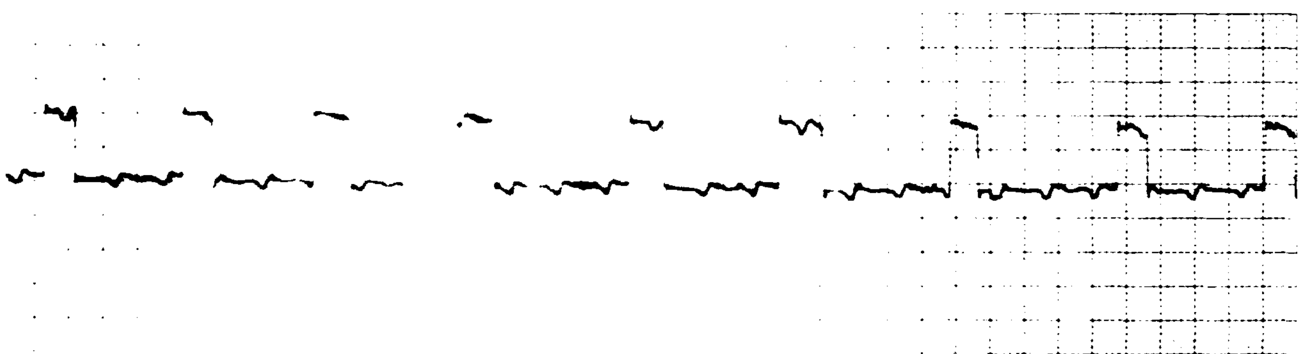
Figure 10. Traces of calibration pulse for simulated ECG transmission/ reception, SD-C60-TDK tape, Sanyo recorder, back-to-back.



(a) Transmitted calibration pulse

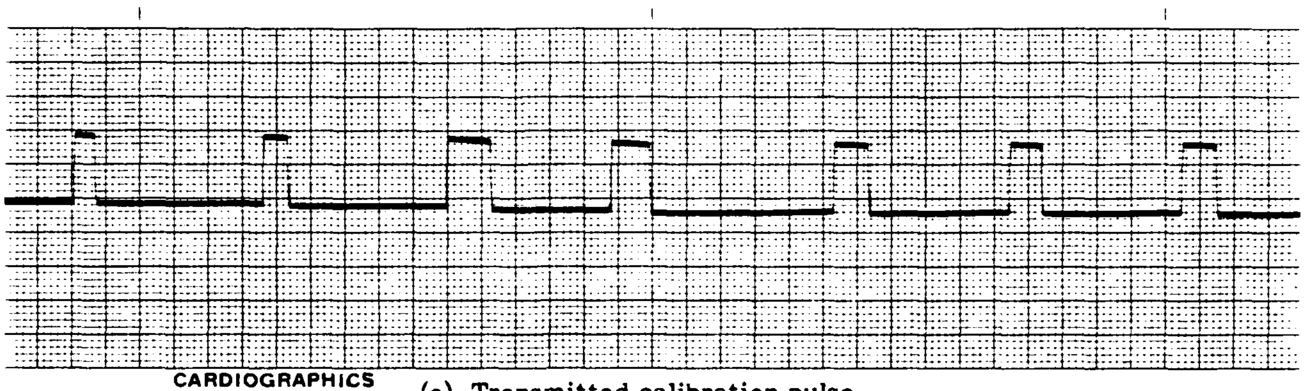


(b) Received calibration pulse

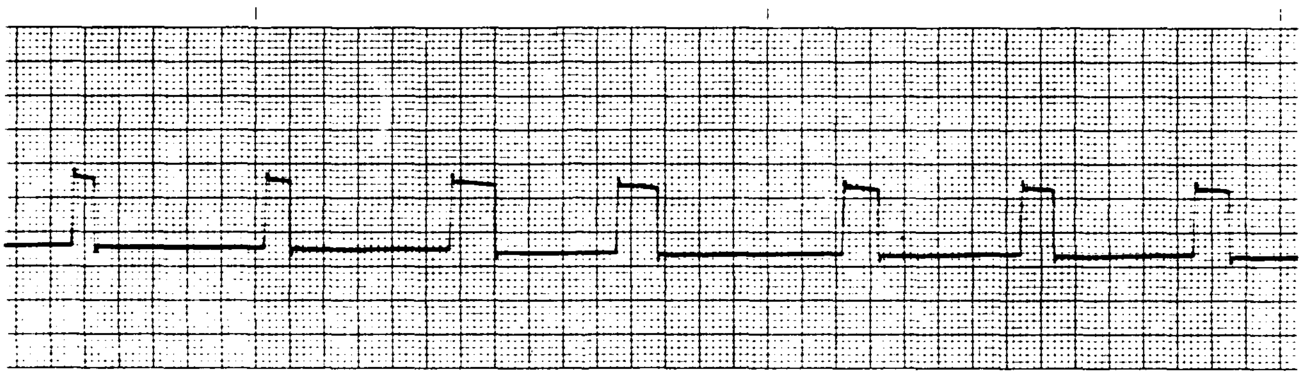


(c) Playback of magnetic recording received calibration pulse

Figure 11. Traces of calibration pulse for simulated ECG transmission/reception. Automatic ECG tape, Sanyo recorder, back-to-back.



(a) Transmitted calibration pulse


(b) Received calibration pulse

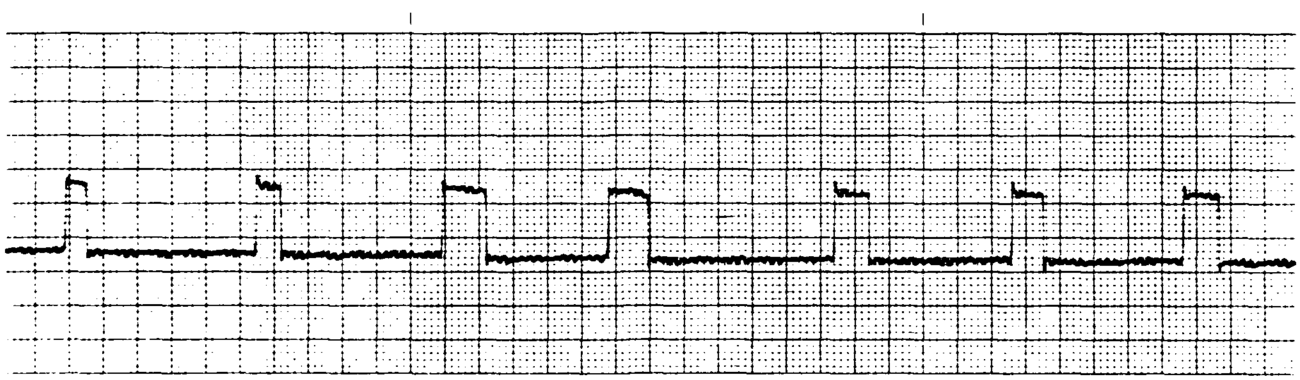
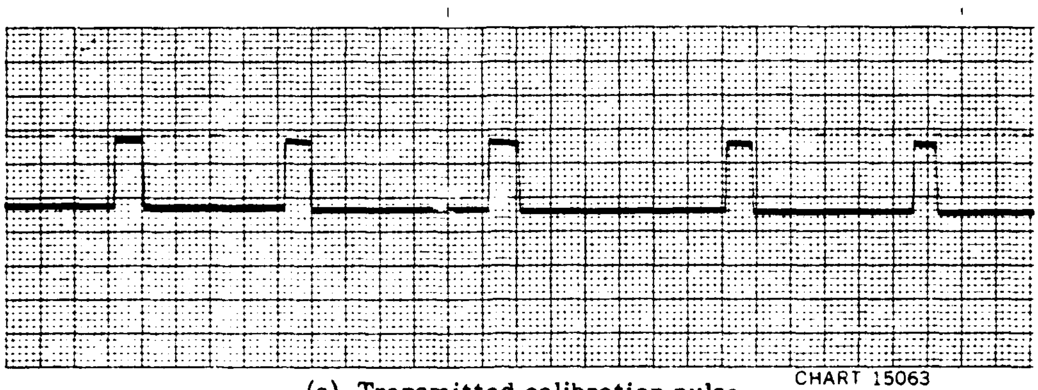
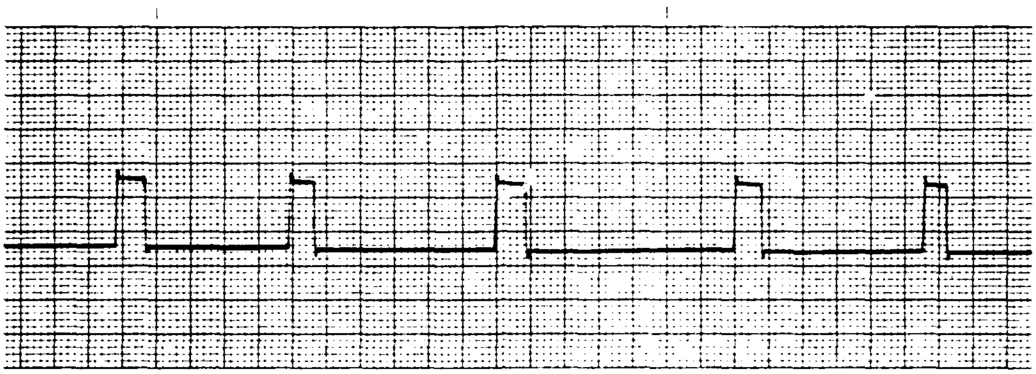

(c) Playback of magnetic recording received calibration pulse

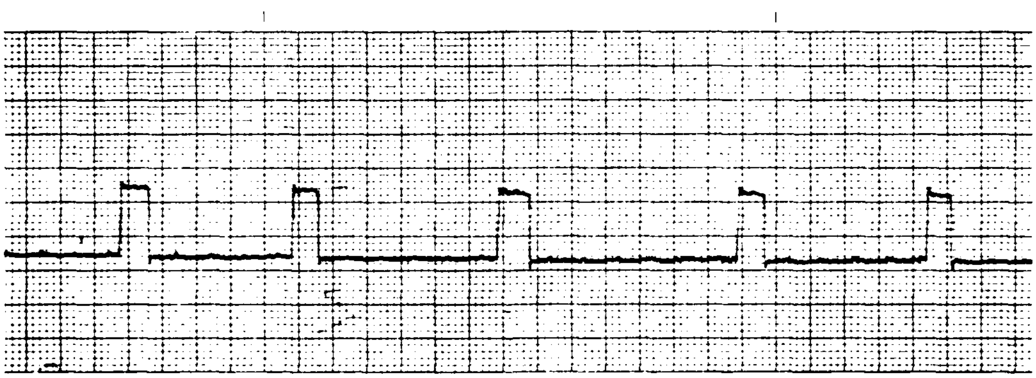
Figure 12. Traces of calibration pulse for simulated ECG transmission/ reception, SD-C60-TDK tape, Panasonic recorder, back-to-back.



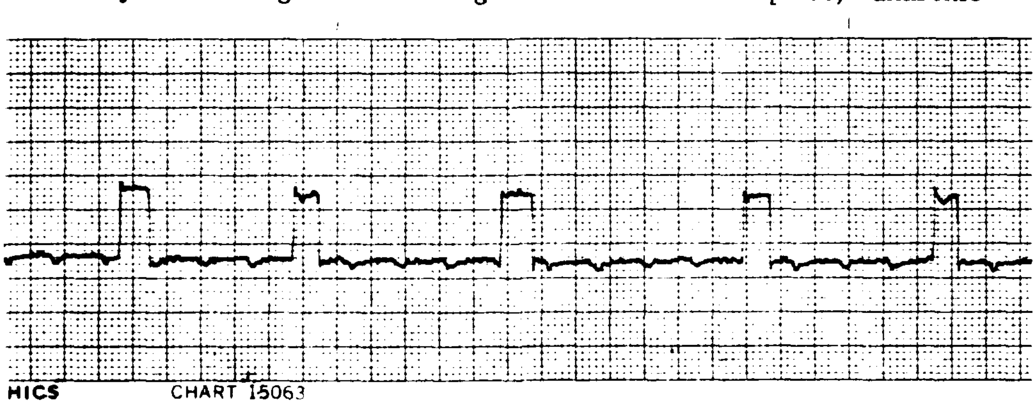
(a) Transmitted calibration pulse



(b) Received calibration pulse

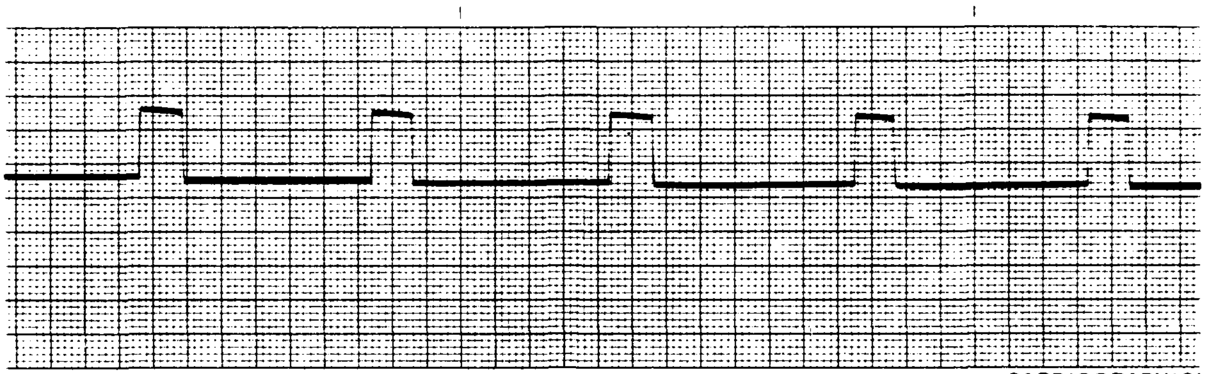


(c) Playback of magnetic recording received calibration pulse, Panasonic

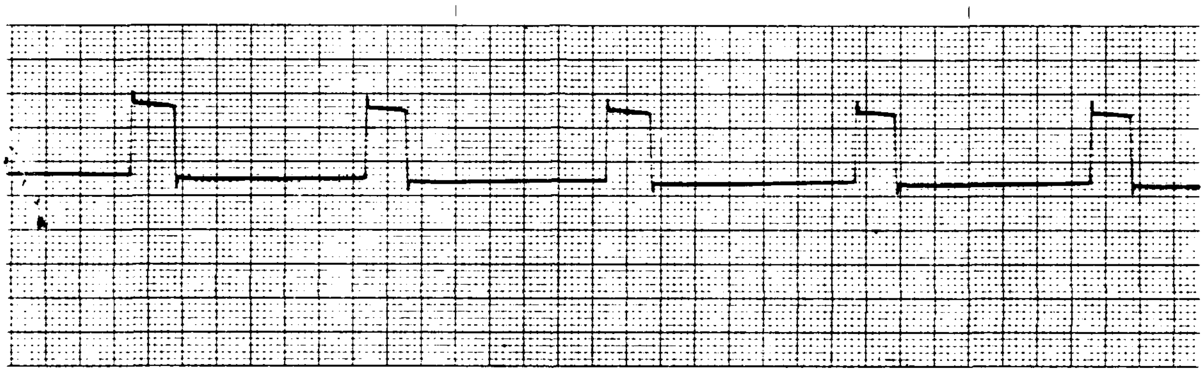


(d) Playback of magnetic recording received calibration pulse, Sanyo

Figure 13. Traces of calibration pulse for simulated ECG transmission/reception, Automatic ECG tape, Panasonic recorder (recorded), back-to-back.



(a) Transmitted calibration pulse



(b) Received calibration pulse

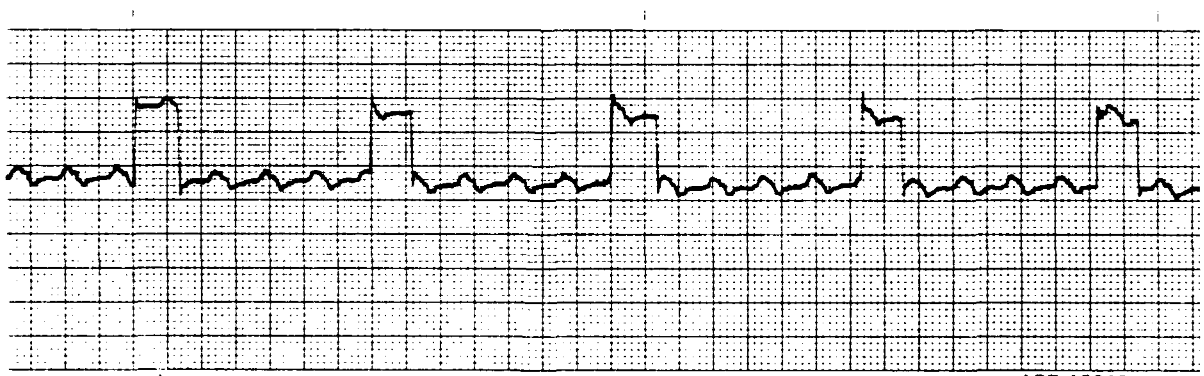

(c) Playback of magnetic recording received calibration pulse

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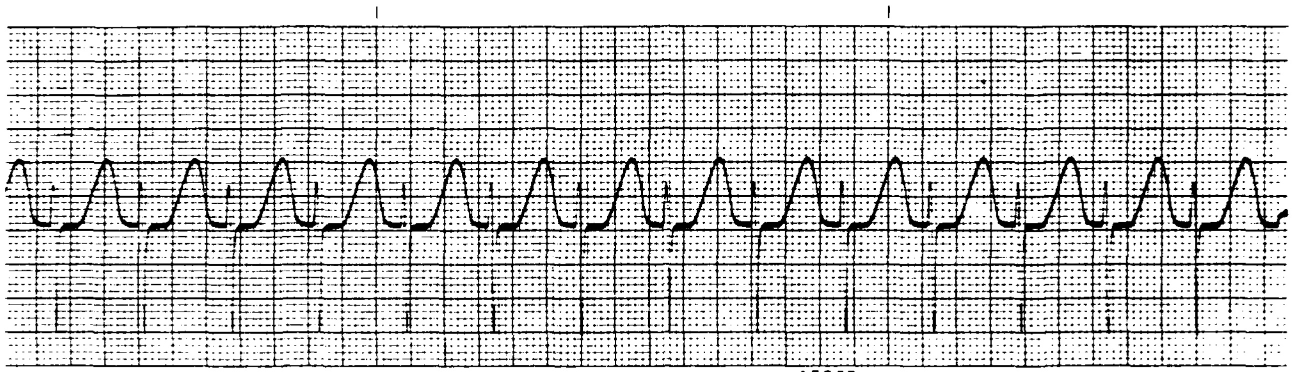
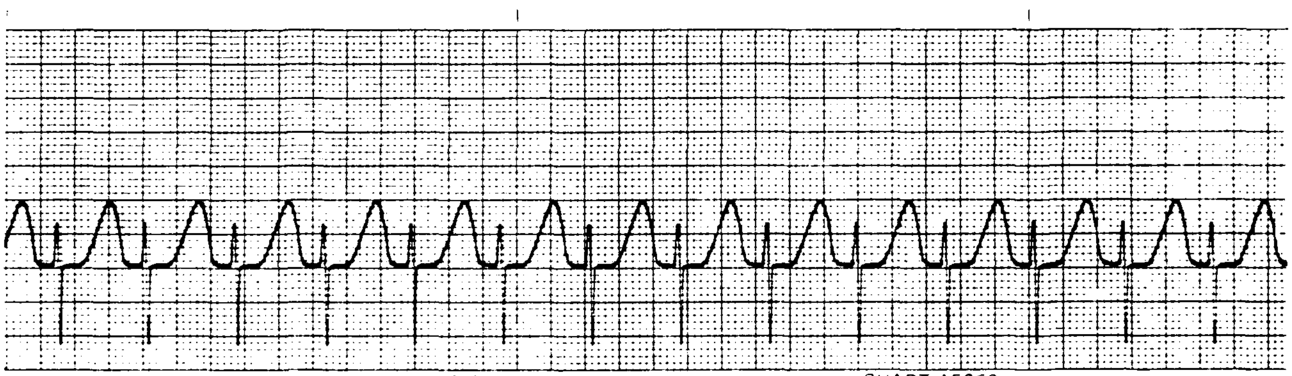
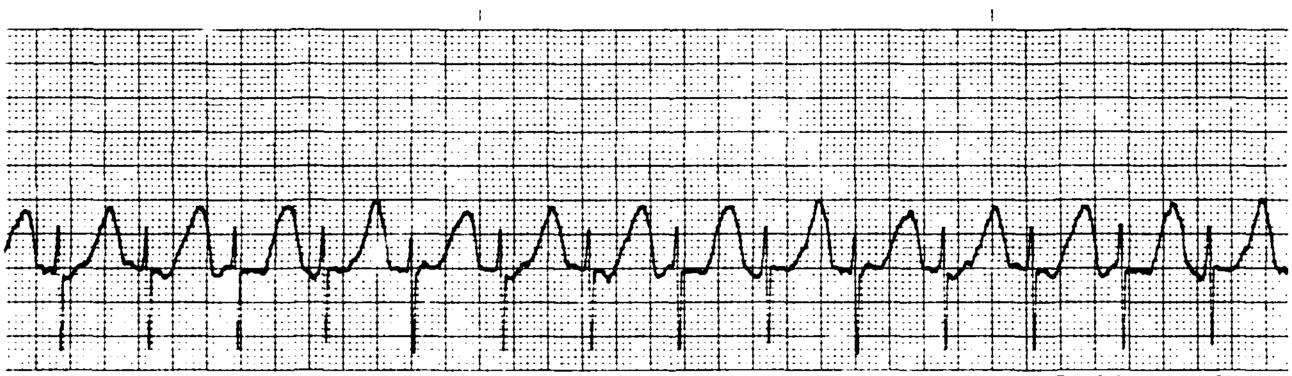
Figure 14. Traces of calibration pulse for simulated ECG transmission/reception, Automatic ECG tape, Sanyo recorder, long distance telephone.



(a) Transmitted ECG signal

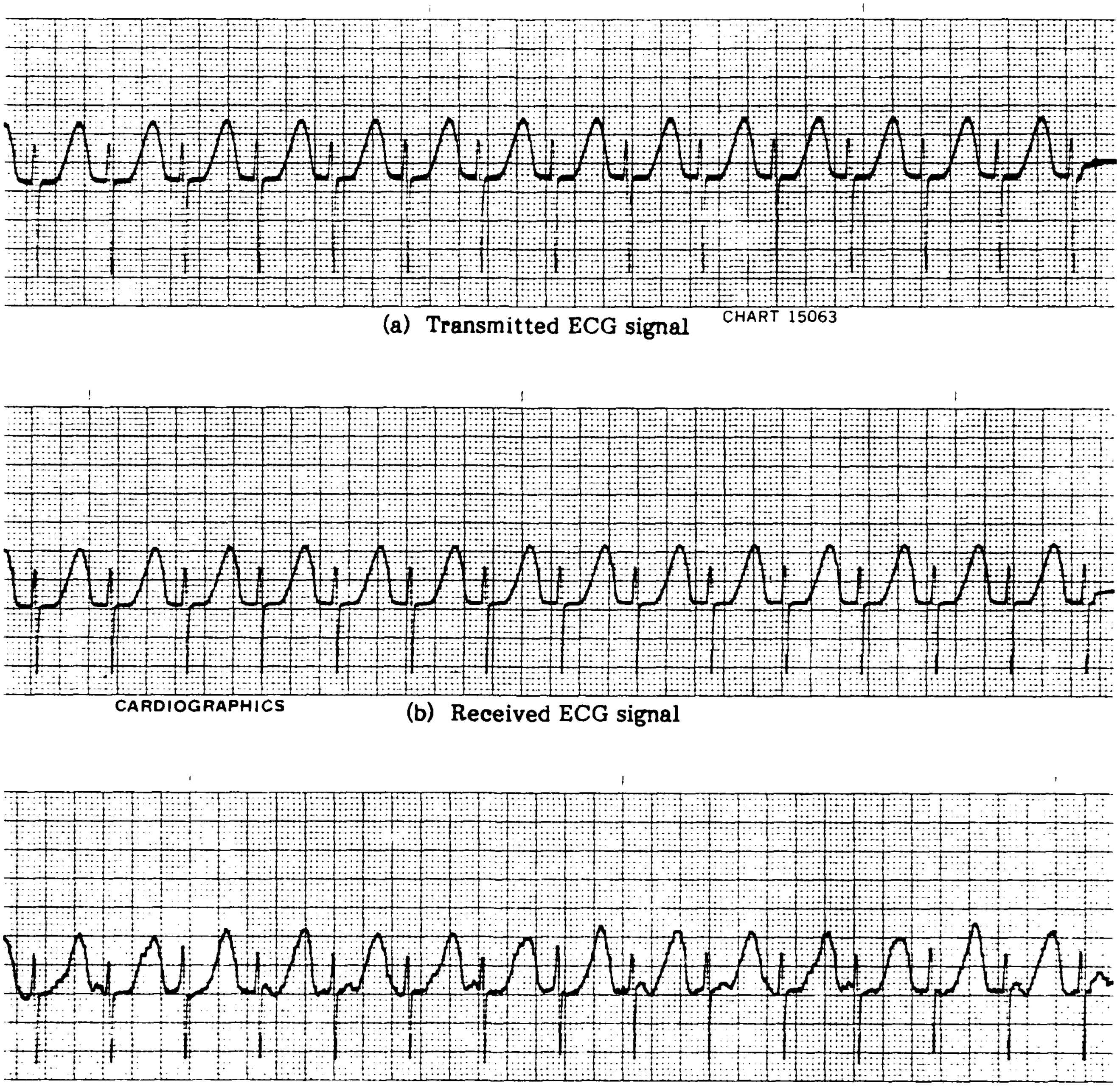


(b) Received ECG signal



(c) Playback of magnetic recording received ECG signal

Figure 15. Signal traces for simulated ECG transmission/reception, Scotch tape, Sanyo recorder, back-to-back.

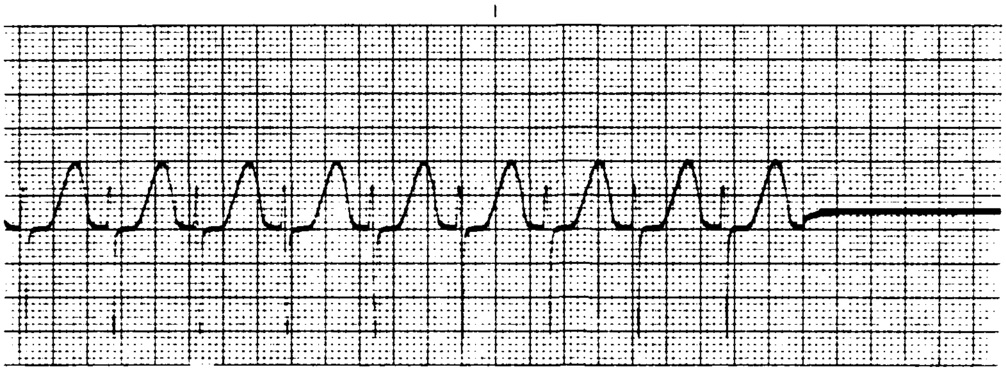


(a) Transmitted ECG signal

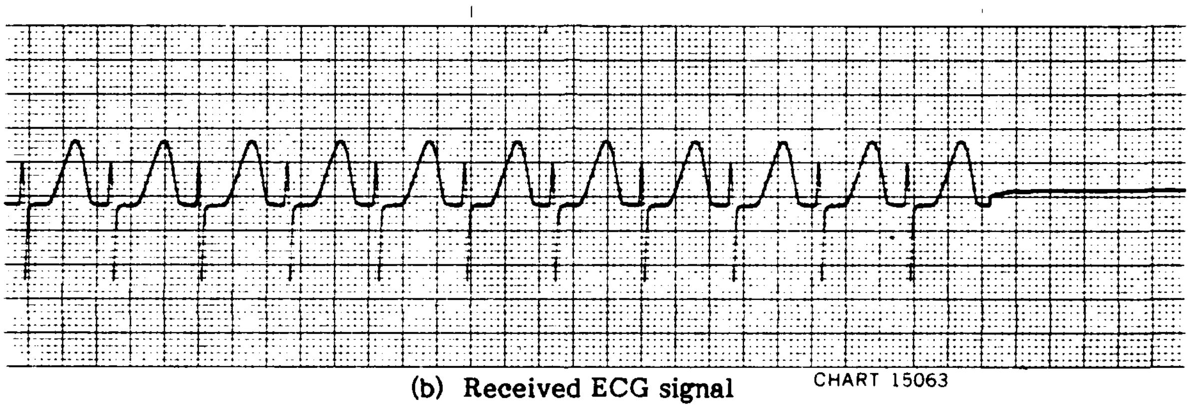
(b) Received ECG signal

(c) Playback of magnetic recording received ECG signal

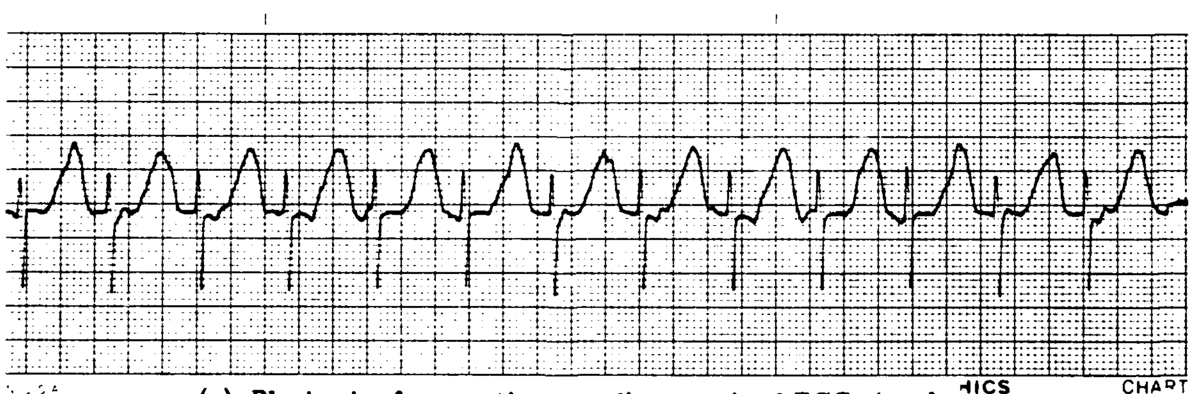
Figure 16. Signal traces for simulated ECG transmission/reception, SD-C60-TDK tape, Sanyo recorder, back-to-back.



(a) Transmitted ECG signal

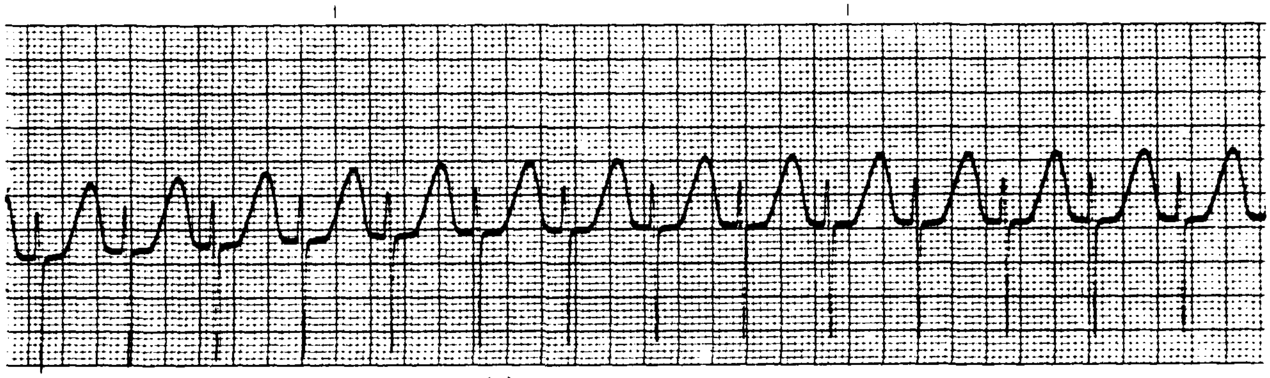


(b) Received ECG signal

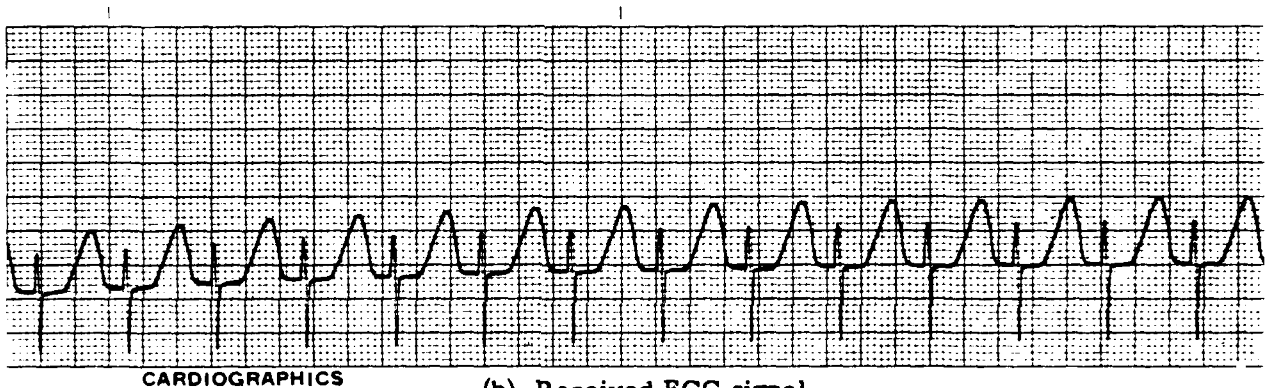


(c) Playback of magnetic recording received ECG signal

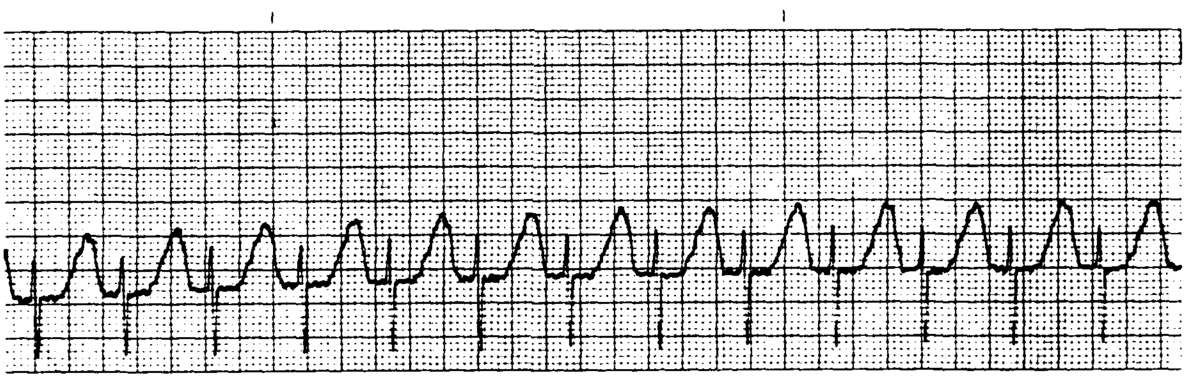
Figure 17. Signal traces for simulated ECG transmission/reception, Automatic ECG tape, Sanyo recorder, back-to-back.



(a) Transmitted ECG signal

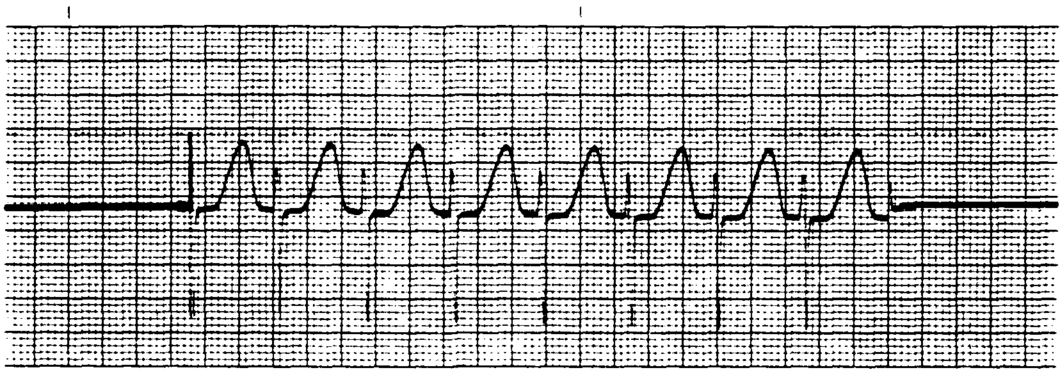


(b) Received ECG signal

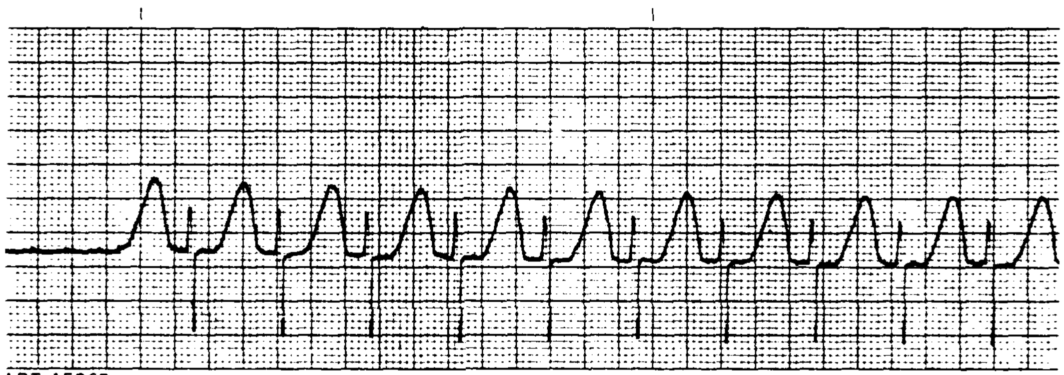


(c) Playback of magnetic recording received ECG signal

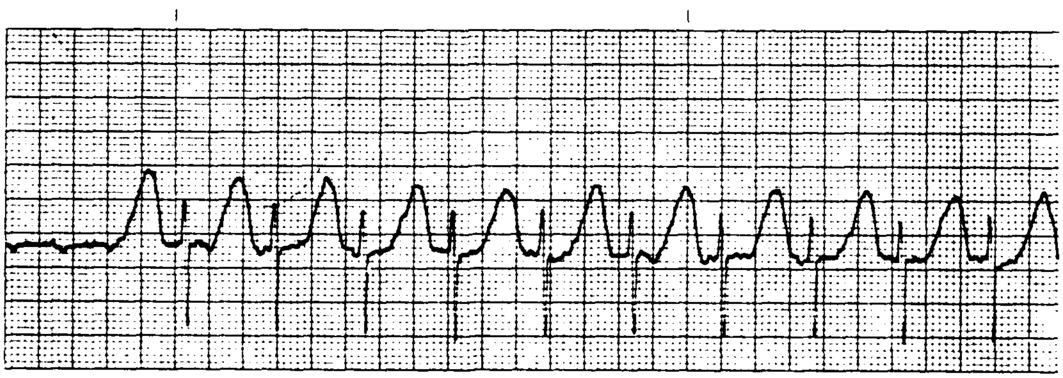
Figure 18. Signal traces for simulated ECG transmission/reception, SD-C60-TDK tape, Panasonic recorder, back-to-back.



(a) Transmitted ECG signal

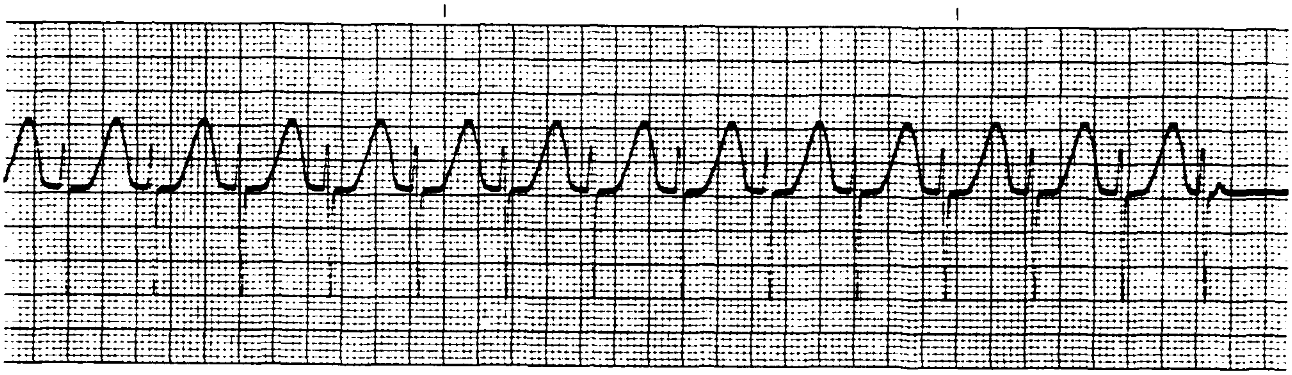


(b) Received ECG signal

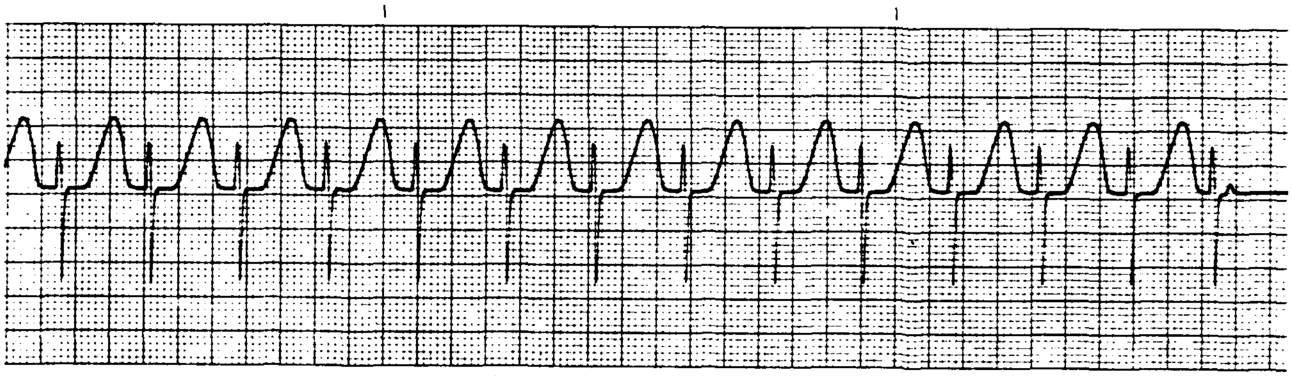


(c) Playback of magnetic recording received ECG signal

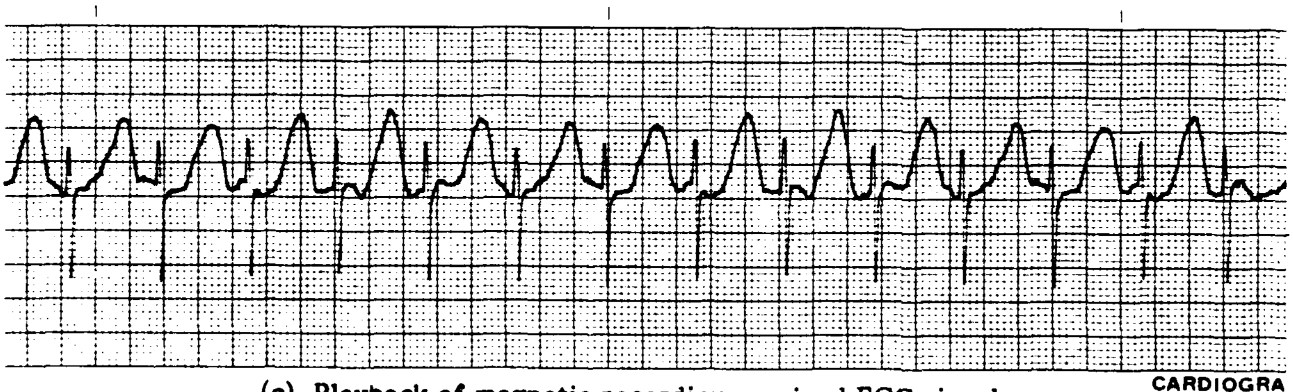
Figure 19. Signal traces for simulated ECG transmission/reception, Automatic ECG tape, Panasonic recorder, back-to-back.



(a) Transmitted ECG signal



(b) Received ECG signal



(c) Playback of magnetic recording received ECG signal

Figure 20. Signal traces for simulated ECG transmission/reception, Automatic ECG tape, Sanyo recorder, long distance telephone.

wow and flutter noise observed for all the variables tested, ie, recording media, recording device, and communication link. Signal distortion varied per test condition and ranged from 25 Hz at 0.1 volt (figure 13) to 3.6 Hz at 0.3 volt (figure 14).

The most dramatic improvement in ECG playback quality was produced by use of the Panasonic recording device. A comparison of figures 11 and 13 illustrates the decrease in noise observed for the Panasonic tape recorder. Figures 13 and 19 provide a comparison of Panasonic and Sanyo strip charts where the received signal was recorded on the Panasonic tape recorder and then played back on the Panasonic and Sanyo tape recorders. Recording the received signal on the Panasonic tape recorder and playing it back on the Sanyo tape recorder decreased the amount of noise observed when compared to recording and playback on the Sanyo (see figures 11 and 17). As seen in figures 11, 14, 17, and 20, the quality of received ECG data for the back-to-back communication link was equal to that of the long distance telephone line, and no noticeable effect was observed for variations in the communication link.

The quality of ECG tape recorder playback via the Sanyo audio tape recorder proved unacceptable for RMDS purposes. Upgrading the tape recorder improved quality, as seen with the use of the Panasonic tape recorder, although some distortion was still observed with this unit.

3.2 HARMONIC DISTORTION

Tests were conducted to determine the amount of harmonic distortion in the received ECG signal caused by the RMDS terminals and communication link during operation in the ECG transfer mode. Figure 21 shows the test setup used. A Wavetek VCG Model III signal generator was used to apply a calibrated signal to the ECG input jack at the transmitting terminal. The RMDS transmitting-receiving terminals were linked in back-to-back, local telephone line, and long distance telephone line configurations. Due to the low signal level out of the ECG output jack at the receiving terminal, a Grass P15 AC preamp was used to boost the signal level to that suitable for analysis. The output of the preamp was measured with a distortion analyzer, Hewlett-Packard Model 311A, and was recorded in percent total harmonic distortion. Prior to RMDS terminal testing, the distortion analyzer was used to measure the harmonic distortion of the signal generator and preamp; these measured 0.35%. All harmonic distortion beyond this value was assumed to be due to the RMDS terminals or communication link.

Original Testing

The values of total harmonic distortion measured for the three transmit-receive terminal links were very similar, averaging 3.7%. The individual values of distortion for the test were as follows:

Communication Link	Percent Harmonic Distortion (including noise contribution)
Back-to-Back	4.0
Local Telephone Line	3.2
Long Distance Telephone Line	4.0

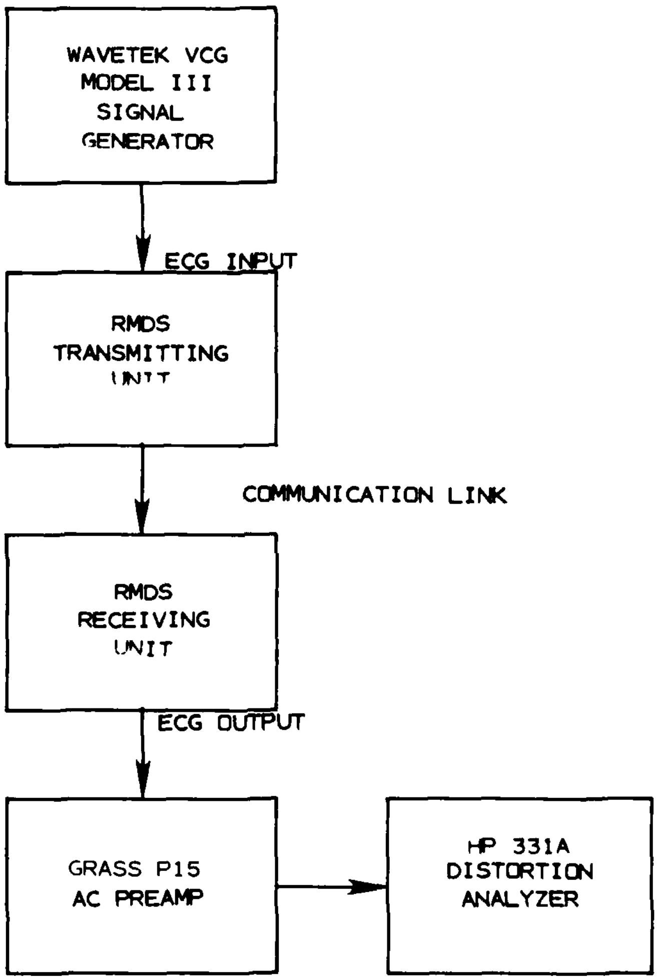


Figure 21. Electrocardiograph (ECG) harmonic distortion measurement test setup.

These levels of harmonic distortion for the three communication links tested, ie, back-to-back, local telephone line, and long distance telephone line, did not degrade the utility of the received ECG signal to any appreciable degree.

Laboratory Retesting

ECG harmonic distortion retesting was performed to determine levels present during tape recorder playback. The same testing setup described earlier in section 3.2 and shown in figure 21 was used for retesting. The signal provided by the Wavetek signal generator was recorded on the Sanyo and Panasonic audio tape recorders and later played back for harmonic distortion measurements. The ECG strip chart recorder within the RMD receiving terminal was used to provide a copy of the received and playback signals of the two recorders. Figure 22 shows samples of the strip charts obtained during this testing period. Listed below are the values of harmonic distortion obtained:

Test Condition	Percent Harmonic Distortion (including noise contribution)
Live Transmission	3.4 to 5.2
Playback on Panasonic	6.0 to 8.0
Playback on Sanyo	15.0 to 17.0

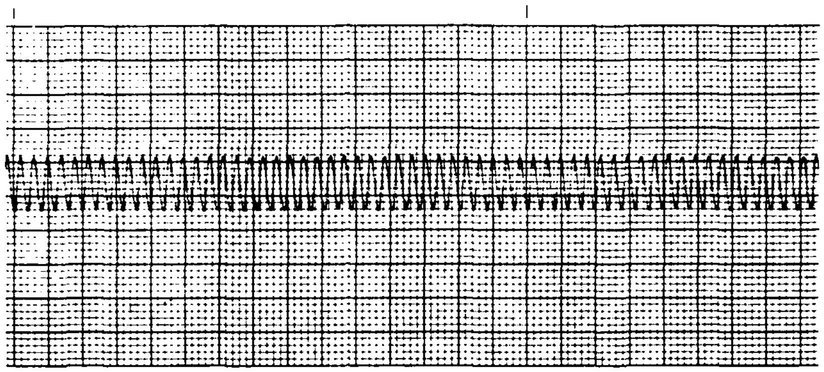
The harmonic distortion measurements for live transmissions were compatible with the original laboratory testing. As seen in figure 22, signal distortion was far greater for the Sanyo playback than for the Panasonic. The playback signal on the Sanyo recorder was being carried on a 0.2 volt peak-to-peak 2 Hz signal, whereas the Panasonic playback signal varied between 2 Hz and 6 Hz at 0.05 volt peak-to-peak. Harmonic distortion measurements for the Sanyo were approximately twice that of the Panasonic, and over three times that of live transmissions.

Harmonic distortion generated by the Sanyo tape recorder produced noticeable and unacceptable distortion level for ECG signal transmission purposes. Harmonic distortion generated by the Panasonic tape recorder did not degrade the utility of the received ECG signal for manual analysis to any appreciable degree.

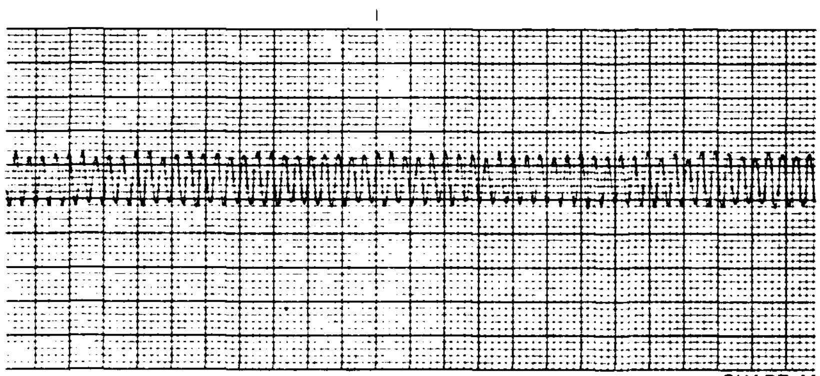
3.3 LINEARITY

Testing was conducted to measure the linearity of signals transmitted by the RMDS terminals operating in the ECG mode. Figure 23 shows the test setup used. Regulated DC voltages from -2.5 to +2.5 volts were applied to the ECG input jack of the transmitting terminal. The transmitting-receiving terminals were linked in a back-to-back configuration. For each transmitted voltage level, a received voltage level was measured from the ECG output jack on the receiving terminal by a high impedance input digital voltmeter with 2% accuracy.

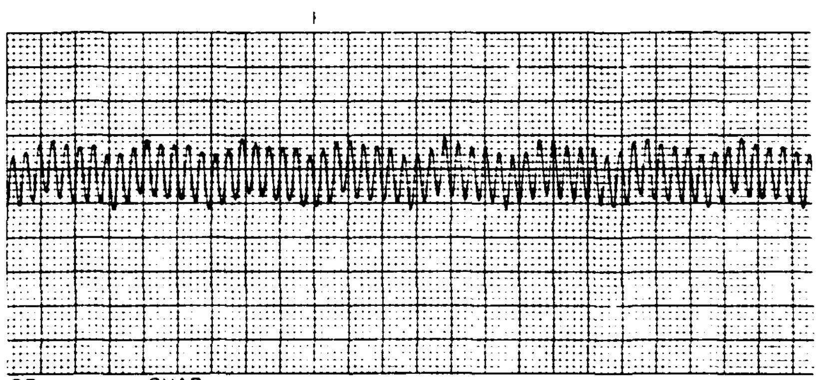
For the purposes of these tests, nonlinearity was defined in a manner similar to that used for D/A converters. Thus, as shown in figure 24, nonlinearity was defined as the maximum deviation of the response curve from a straight line through the end points of the waveform, divided by the peak-to-peak distance between the end points of the waveform.



(a) Received live



(b) Playback Panasonic



(c) Playback Sanyo

Figure 22. ECG signal traces for harmonic distortion testing.

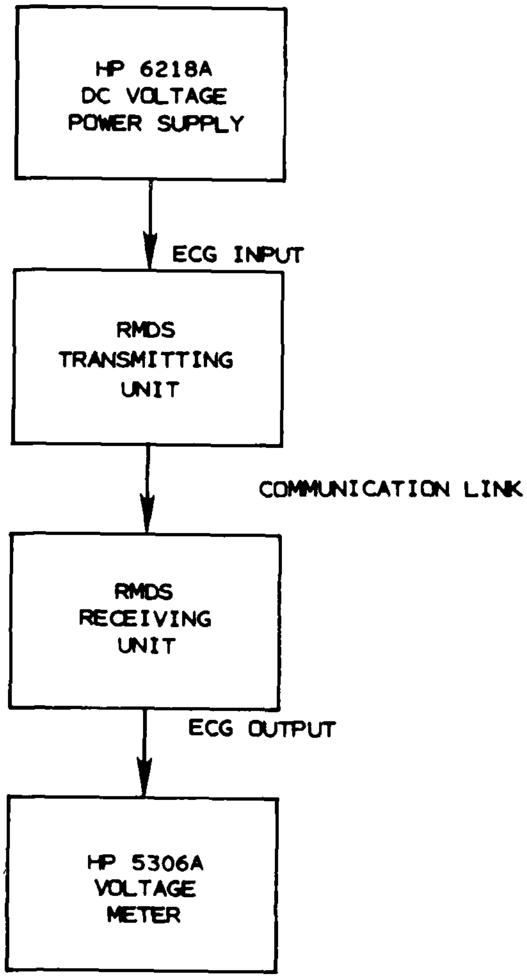


Figure 23. ECG linearity test setup.

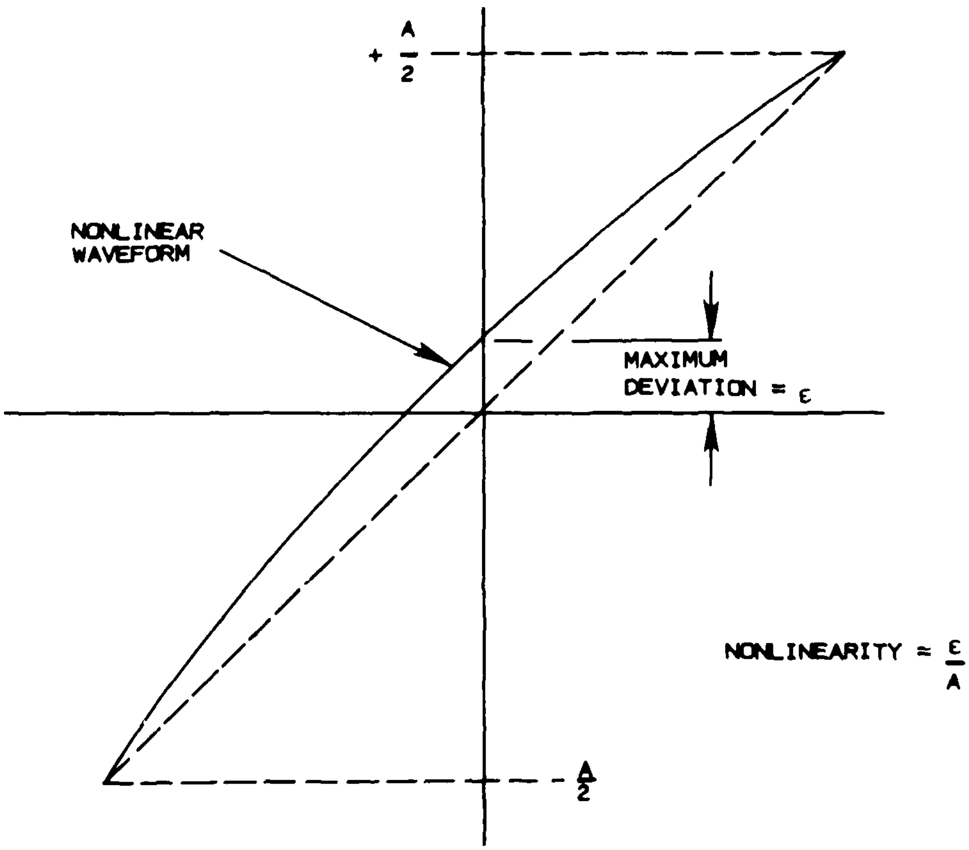


Figure 24. Nonlinearity definition method.

Original Testing

Table 3 lists the voltages transmitted versus voltages received. Figure 25 shows a plot of voltage transmitted versus voltage received. From this graph a value of approximately 10% nonlinearity was computed for the RMDS terminals operating in the ECG mode.

Voltage Transmitted	Voltage Received
-2.5	-0.15
-2.0	-0.135
-1.5	-0.12
-1.0	-0.10
-0.5	-0.08
0.0	-0.057
+0.5	-0.034
+1.0	-0.005
+1.5	+0.025
+2.0	+0.055
+2.5	+0.095

Table 3. ECG linearity measurements of voltages transmitted versus voltages received (original testing).

The value obtained for nonlinearity in this test (10%) was noticeably larger than the less than 5% obtained in the Colorado Video, Inc. tests. The different methods for determining linearity between the two tests may account for the results. In the CVI testing, a 1.0 volt peak-to-peak, 0.1 Hz ramp signal was recorded on an HP 1500B ECG recorder and then analyzed for linearity. For the testing reported herein, constant voltage levels between -2.5 and +2.5 volts were applied to and recorded directly from the RMDS terminal. It should be noted that the attenuation of signal which occurred during this testing, ie, 2.5 volts transmitted versus 0.15 volt received, was due to signal manipulation for equipment compatibility. Retesting of the ECG linearity was conducted o resolve the differences in results.

Laboratory Retesting

The method used for retesting of ECG linearity was the same as that described earlier in section 3.3 and shown in figure 23. Table 4 lists the voltages transmitted versus voltages received, and figure 26 plots the voltages transmitted versus voltages received. From this graph a value of approximately 12% nonlinearity was computed for the RMDS terminals operating in the ECG mode for input signals ranging from +2.5 to -2.5 volts (see line segment a, figure 26).

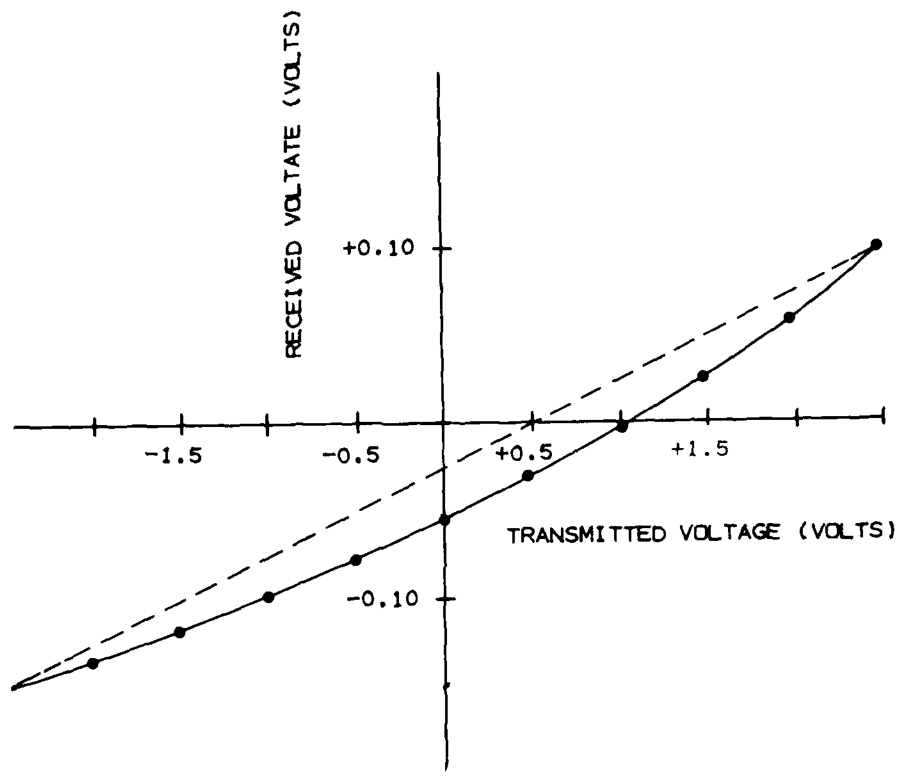


Figure 25. Original ECG linearity testing.

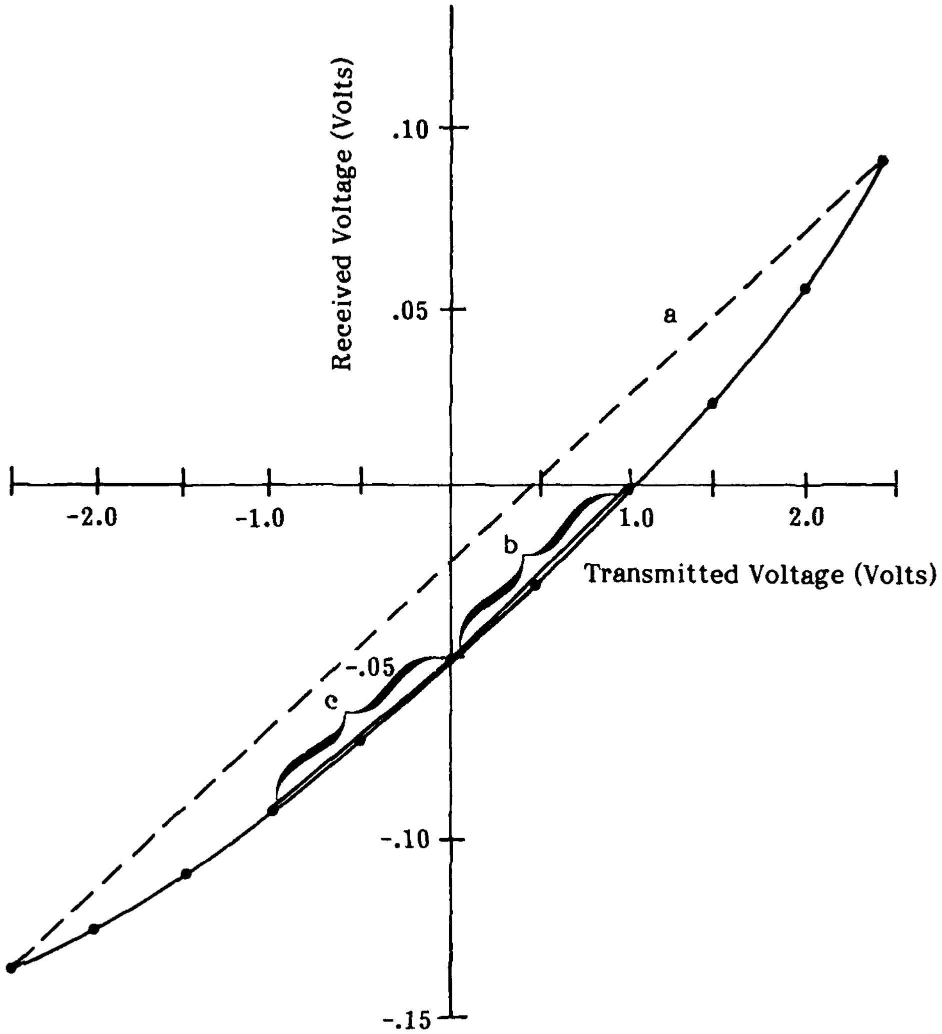


Figure 26. ECG linearity retesting.

Voltage Transmitted	Voltage Received
-2.5	-0.138
-2.0	-0.129
-1.5	-0.112
-1.0	-0.094
-0.5	-0.074
0.0	-0.052
+0.5	-0.029
+1.0	-0.003
+1.5	+0.025
+2.0	+0.057
+2.5	+0.092

Table 4. ECG linearity measurements of voltages transmitted versus voltages received (retesting).

The value obtained for nonlinearity in this test (12%) was compatible with the value obtained during the original laboratory testing period (10%) over the same range of input voltages. A value of approximately 3% and 5% nonlinearity was computed from figure 26 (see line segments b and c) for input signals ranging from 0.0 to +1.0 volt and 0.0 to -1.0 volt, respectively. These values of nonlinearity were compatible with the values obtained in the Colorado Video, Inc. tests for a similar range of input signals.

Signal distortion caused by system nonlinearity, ie, amplitude and harmonic distortion, can be minimized by limiting the utilized range of input signal amplitudes. Increases in nonlinearity normally accompany increases in signal amplitude, with the largest amount of distortion occurring in large negative and positive input signals. Limiting ECG input signal amplitude to a 1.0 volt peak-to-peak range should reduce system nonlinearity to an acceptable level without limiting ECG utility.

3.4 NOISE LEVEL

Testing was performed to determine the noise levels, including system drift, in the received signals for RMDS terminals operating in the ECG signal transfer mode. Figure 27 shows the test setup. A shorted plug was placed on the ECG input jack on the transmitting terminal. The RMDS transmitting and receiving terminals were linked in back-to-back, local telephone line, and long distance telephone line configurations. The ECG output of the receiving terminal was monitored with an oscilloscope, and measurements of RMS noise levels were obtained at the receiving terminal.

Original Testing

High ambient levels of rf and 60 Hz noise were found to exist at the NOSC facility where the testing was conducted. A 3-foot twisted pair transmission line, terminated in 600 ohms, was used for the measurement of the levels and characteristics of this noise. Three types of noise were identified. First, a random 1.5 to 2.0 volt peak-to-peak noise spike of unknown origin frequently occurred during the tests. Second, a daily periodic 1 MHz communications signal from an unknown source,

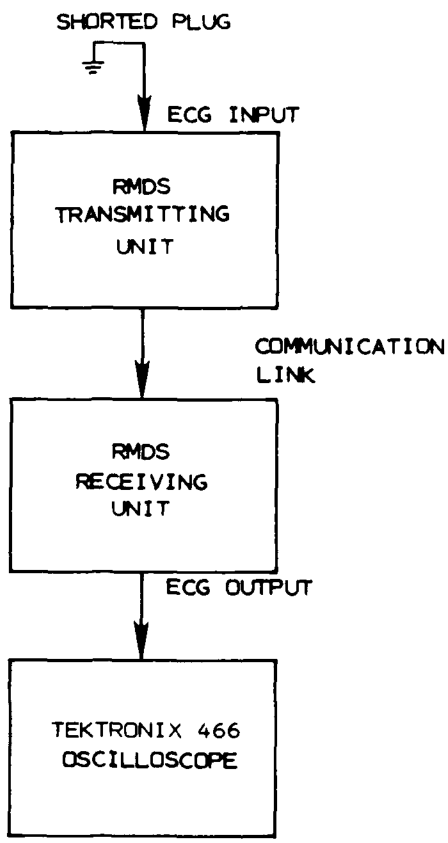


Figure 27. ECG noise level measurement setup.

with coding of 20 MHz and voltage amplitude of 30-60 mV, was present. Finally, a 60 Hz noise of 10 mV occurred randomly. The questionable reliability of all planned noise measurements was due to the masking effect of these noted noise signals. To obtain more accurate measurement, an rf shielded room would be required.

To attenuate the noise mentioned above, a termination capacitor and load were shunted across the input to the oscilloscope and measurements were recorded as received RMS noise. The RMS noise levels were as follows:

Back-to-Back	7.5 mV
Local Telephone Line	30.0 mV
Long Distance Telephone Line	50.0 mV

These levels show a generally increasing noise level with increasing complexity of the communication link, as might be expected. No noticeable drift in the received voltage level was noted for any of the communication links.

When the above noise values are compared to an ECG signal referenced at 1.0 volt, the long distance telephone line communication link would represent only 5% noise level, or a signal-to-noise ratio of 26.0 dB. This indicates that the RMDS is capable of ECG signal transmission with typical telephone noise levels, resulting in no noticeable received signal degradation.

Laboratory Retesting

High ambient levels of rf and 60 Hz noise generated some doubt as to the reliability of the original RMDS noise measurements. In an attempt to validate the original noise measurements, all RMDS noise testing was repeated during the laboratory retesting period. During this retesting, additional testing was performed to evaluate the effect of tape record usage. An rf shielded room was not available during the retesting period. However, retesting was performed at the same NOSC facility and under conditions similar to those of the original testing.

Again, high ambient levels of rf and 60 Hz noise were found to exist at the NOSC facility where the testing was conducted. A 3-foot twisted pair transmission line terminated in 600 ohms was used for the measurement of the levels and characteristics of this noise. Three types of noise were identified:

- 17 mV peak-to-peak, 5 kHz signal carrying a 100 MHz signal
- 0.2 V peak-to-peak, 2 kHz square wave
- 0.6 V peak-to-peak, 60 Hz sine wave

Additional noises were observed during the testing period, but because of their random and periodic nature, they were not measured.

Two steps were taken in an attempt to minimize the effects of the noise mentioned above on RMDS noise measurements. First, the NOSC facility was monitored during various times of the day and days of the week to determine the period of time with the least amount of ambient noise. Sunday morning between 2 and 6 AM had reduced levels of ambient noise and was chosen as the testing period. Second, a termination capacitor (0.15 μF) and load (560 ohms) were shunted across the input to the oscilloscope to reduce the effects of ambient noise levels on measurements.

ECG noise measurements were recorded as received RMS noise by means of a dual-trace oscilloscope procedure. Listed below are the values obtained during laboratory retesting:

Communication Link	RMS Noise (mV) ECG Live	RMS Noise (mV) ECG Tape Playback
Back-to-Back	6.0	6.5
Local Telephone Line	4.0	4.0
Long Distance Telephone Line	6.0	6.0

The noise measurements obtained for the various communication links and tape recorder playback were very similar. The noise measurement for the back-to-back configuration is comparable to the original testing (7.5 mV), whereas local and long distance telephone line measurements were greatly reduced from the 30 mV and 50 mV readings, respectively, obtained during the original testing. The reduction in noise observed for local and long distance telephone lines may be due to the time of day in which the testing was performed. It was expected that good telephone line conditions could be obtained between 2 and 6 AM on Sunday, when traffic usage is low. The original testing was performed during working hours of the week, when a larger amount of telephone line traffic occurs.

Comparing the above noise values to an ECG signal referenced to 1.0 volt showed that even under the poorest condition tested (back-to-back, tape playback), the noise level represented only 0.65% of the signal, or a signal-to-noise ratio of 43.7 dB. This indicated that the RMDS was capable of ECG signal transmission and tape playback with typical telephone noise levels, with no noticeable received signal degradation.

3.5 RECEIVER SENSITIVITY

Testing was conducted only during the retesting period to determine the sensitivity of the RMDS terminal in the ECG receive mode to added noise and reduced input signal levels. Figure 28 shows the test setup. A 1.0 volt 25 Hz signal was applied to the ECG input jack at the transmitting terminal, with the RMDS terminals wired in a back-to-back configuration. Reduction in the signal levels and the addition of noise were performed between the receiving and transmitting terminals on the transmission line. Because of the nature of the transmission line, all measurements of signal manipulation were obtained from the primary side of a single-ended-to-balanced transformer (600Ω-to-600Ω) associated with the variable gain noise mixer interface terminal. The MFE strip chart recorder at the receiving terminal was used to monitor the ECG output in hard-copy form.

Starting with a minimum amount of attenuation of the transmission line signal, the signal level was gradually decreased until the ECG system defaulted. Figures 29, 30 and 31 show the strip charts obtained at the receiving terminal during signal level attenuation testing. At the start of testing, the minimum signal attenuation level was

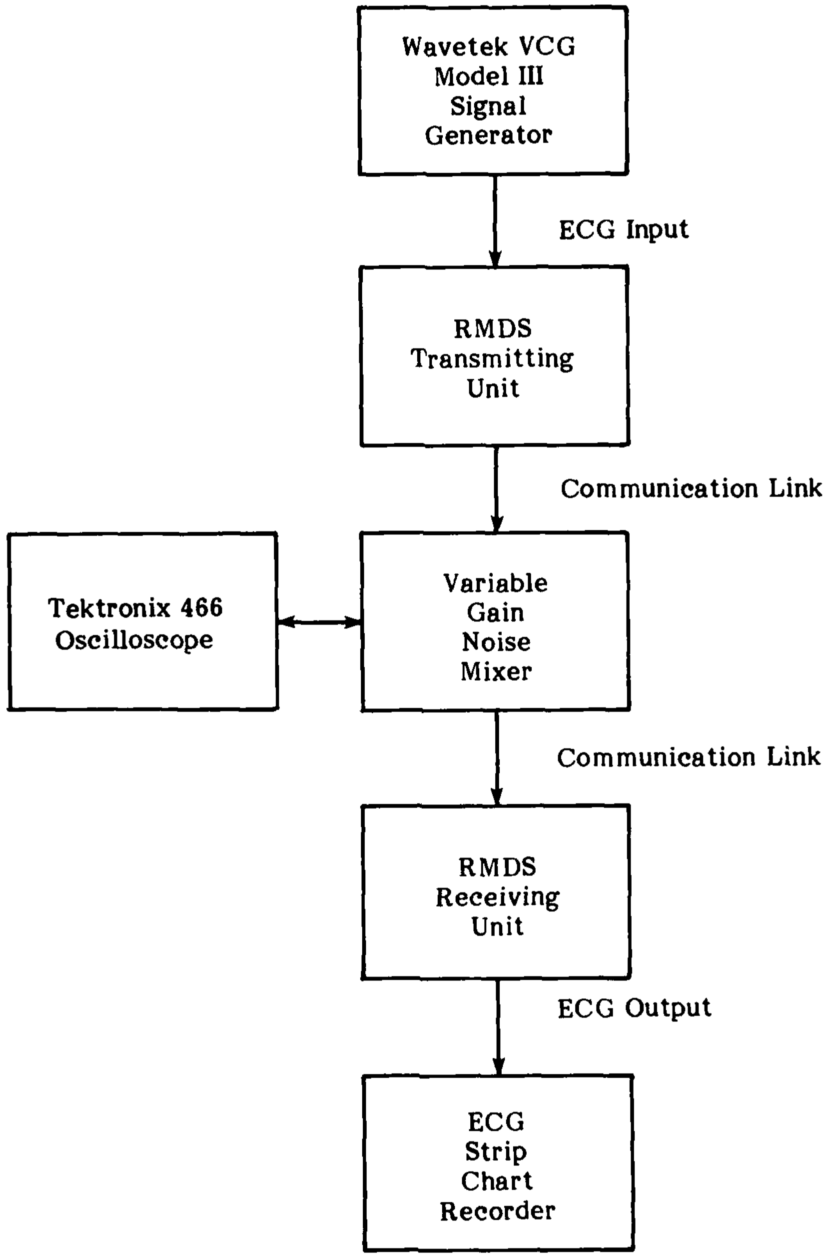
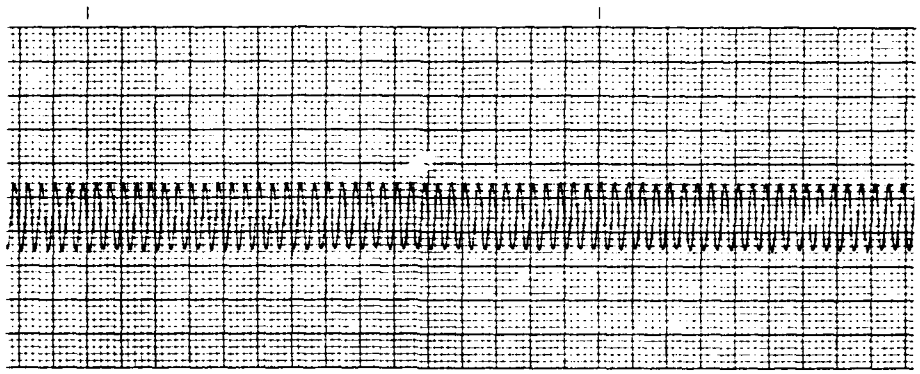
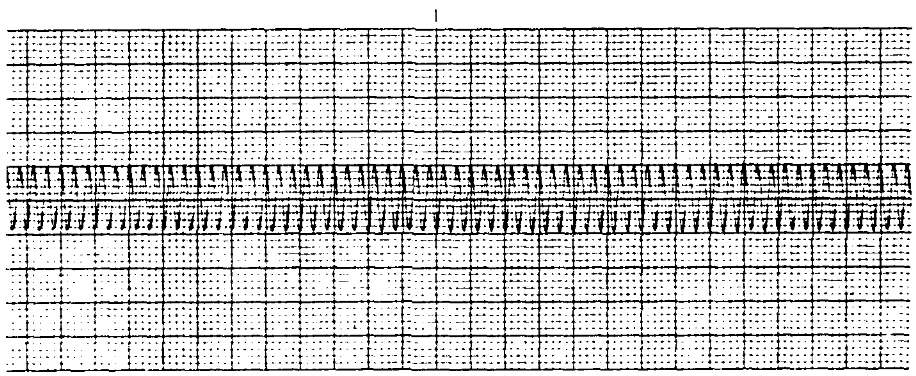


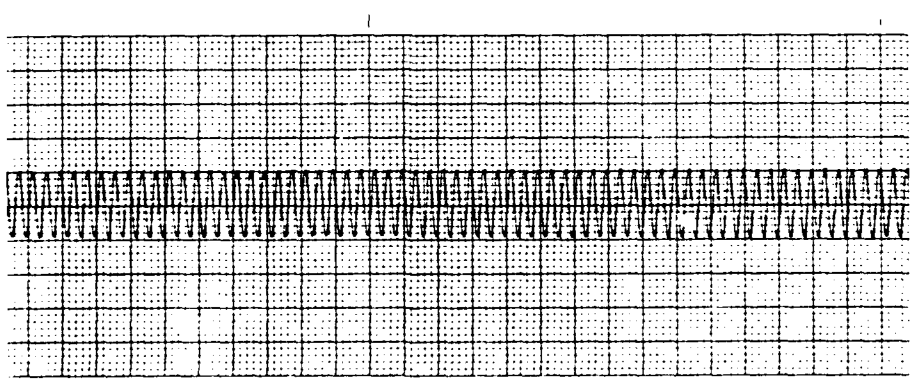
Figure 28. Receiver sensitivity test setup.



(a) 160 mV peak-to-peak (minimum signal attenuation)

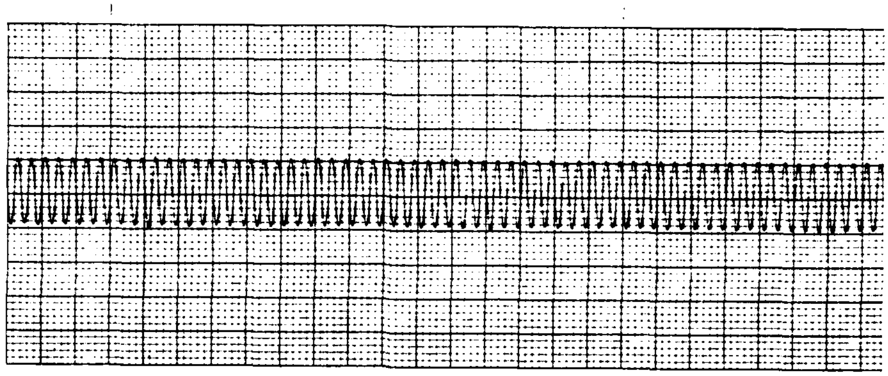


(b) 120 mV peak-to-peak

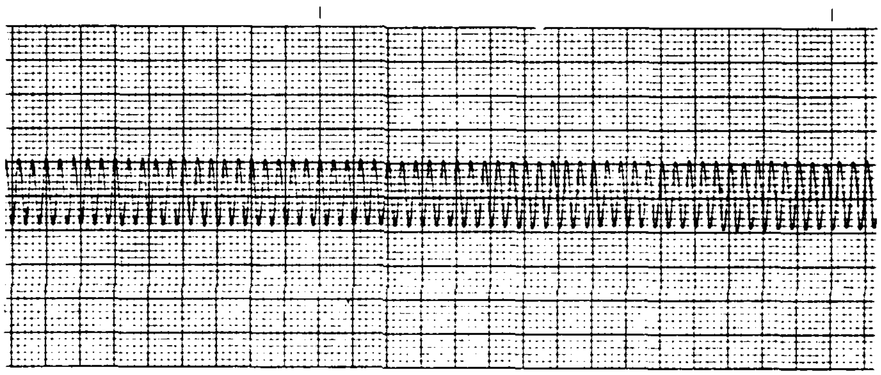


(c) 80 mV peak-to-peak

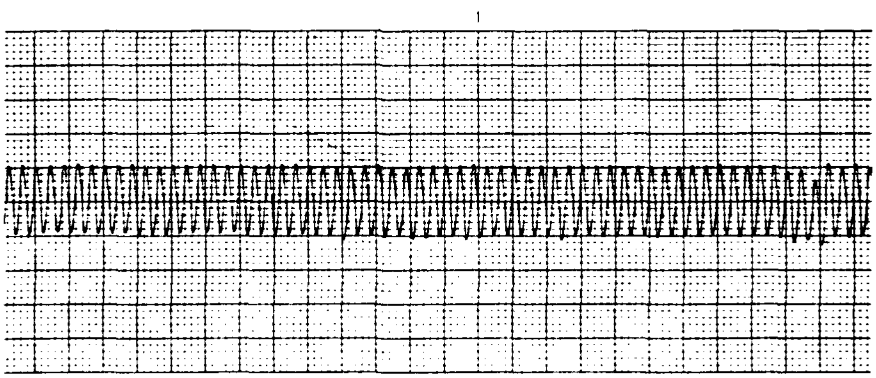
Figure 29. ECG signal traces for receiver sensitivity testing, with 160 mV (minimum signal attenuation) pk-pk, 120 mV pk-pk, and 80 mV pk-pk signal levels.



(a) 60 mV peak-to-peak

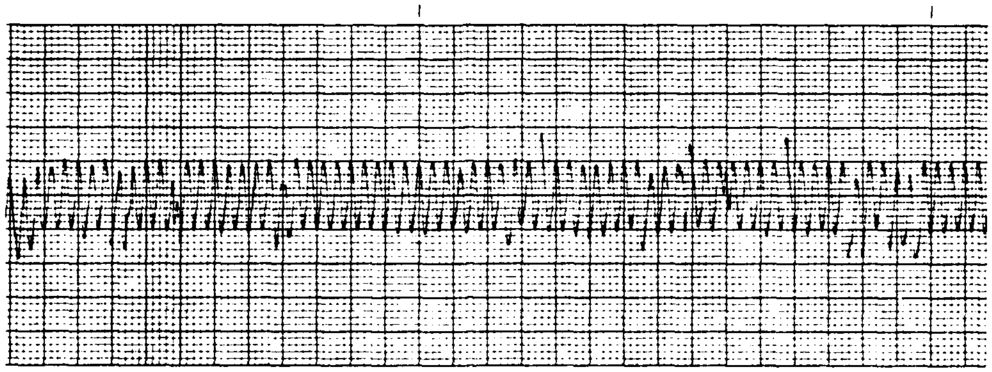


(b) 50 mV peak-to-peak

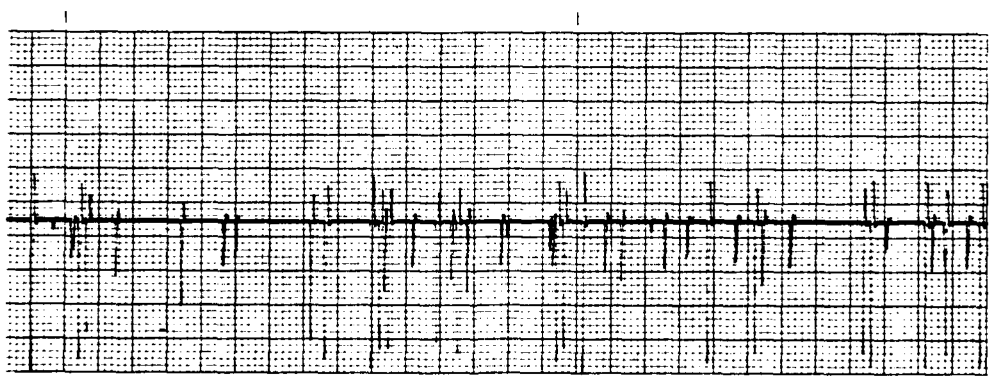


(c) 45 mV peak-to-peak

Figure 30. ECG signal traces for receiver sensitivity testing, with 60 mV pk-pk, 50 mV pk-pk, and 45 mV pk-pk signal levels.



(a) 42 mV peak-to-peak

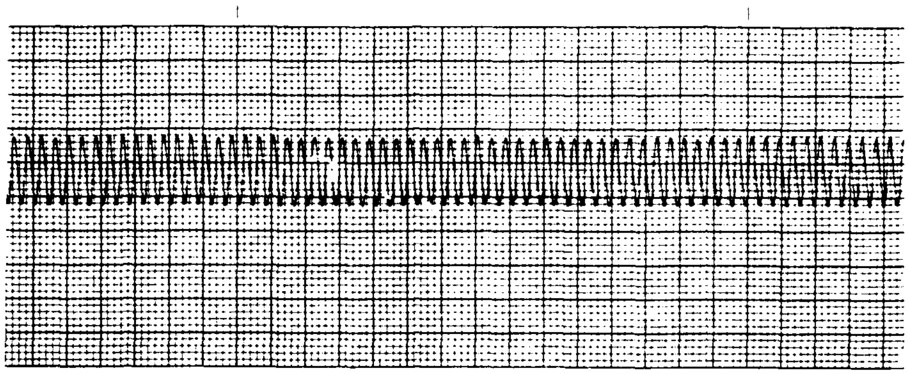


(b) 40 mV peak-to-peak

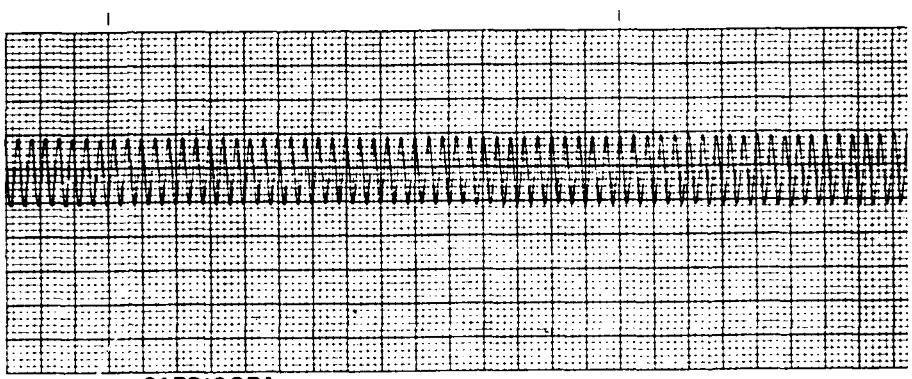
Figure 31. ECG signal traces for receiver sensitivity testing, with 42 mV pk-pk and 40 mV pk-pk signal levels.

160 millivolts peak-to-peak. The ECG system did not fail to operate completely until the signal had been reduced to 40 millivolts peak-to-peak (figure 31), one fourth the initial signal level. This represents a dynamic range of 12 dB for signal attenuation. Prior to complete failure of the ECG system, signal amplitude distortion was observed that ranged from "slight" at the 50 millivolt peak-to-peak signal level (figure 30) to "extensive" at the 42 millivolt peak-to-peak signal level (figure 31).

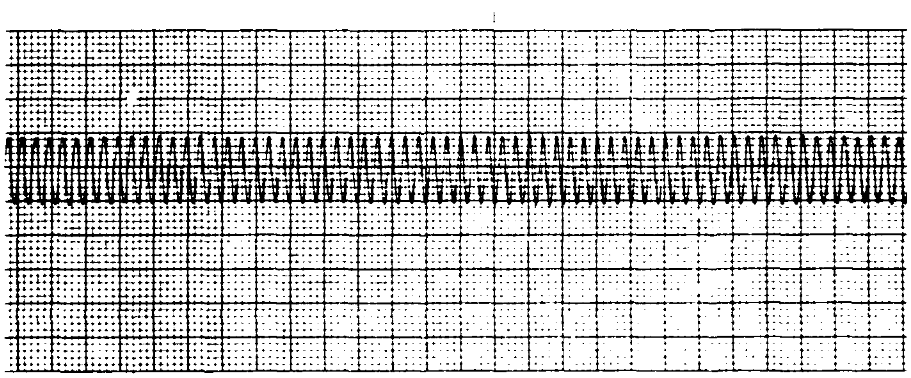
After setting the transmission line signal to the minimum attenuation level, white noise was gradually added until complete system failure occurred. The amount of noise initially found on the transmission line was 30 millivolts RMS at the output of the variable gain noise mixer interface unit. Figures 32 through 35 show the strip charts obtained at the receiving terminal during noise addition testing. As can be seen in figure 35, a slight amount of amplitude distortion was observed in the received signal prior to system failure. The ECG system failed to operate with the addition of 525 millivolts RMS noise to the transmission line. This would indicate that the RMDS was sensitive enough to receive ECG transmission with typical telephone noise levels and attenuation distortion.



(a) 0 mV noise added

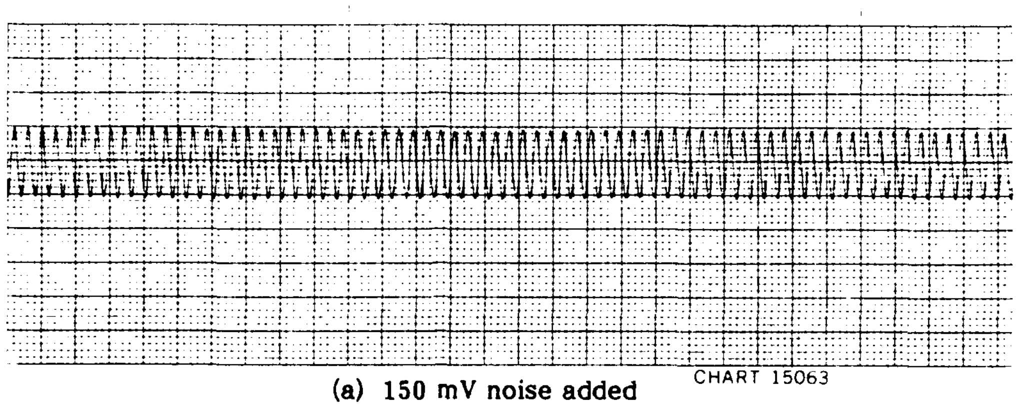


(b) 100 mV noise added

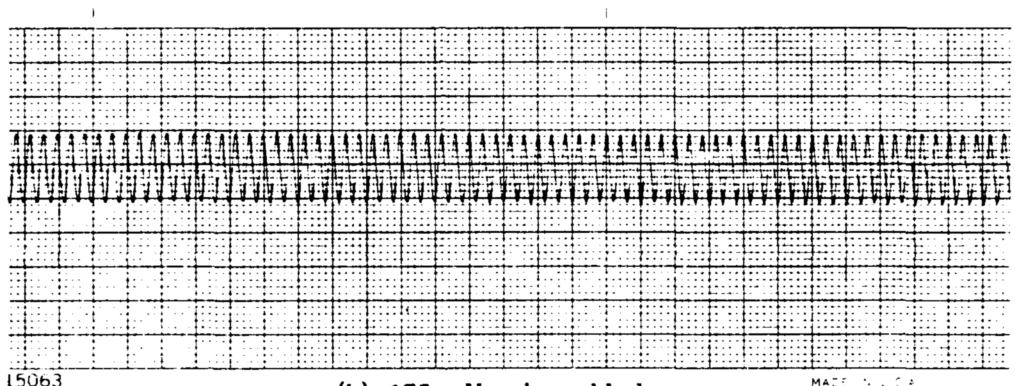


(c) 125 mV noise added

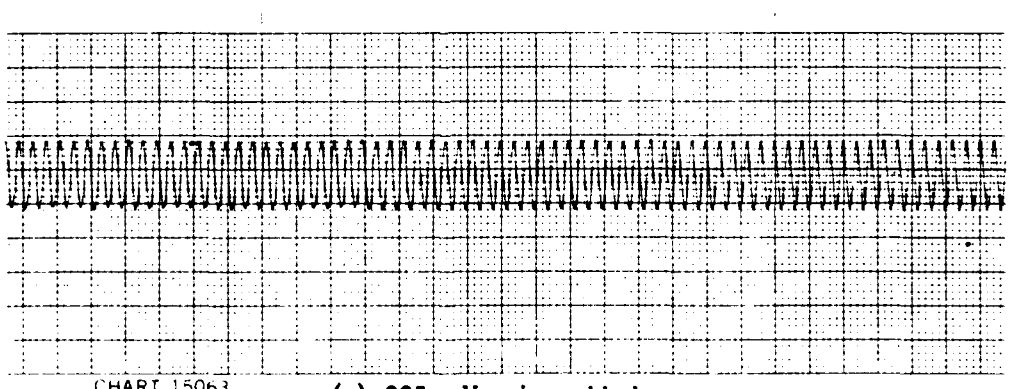
Figure 32. ECG signal traces for receiver sensitivity testing, with 0 mV, 100 mV, and 125 mV rms noise added.



(a) 150 mV noise added

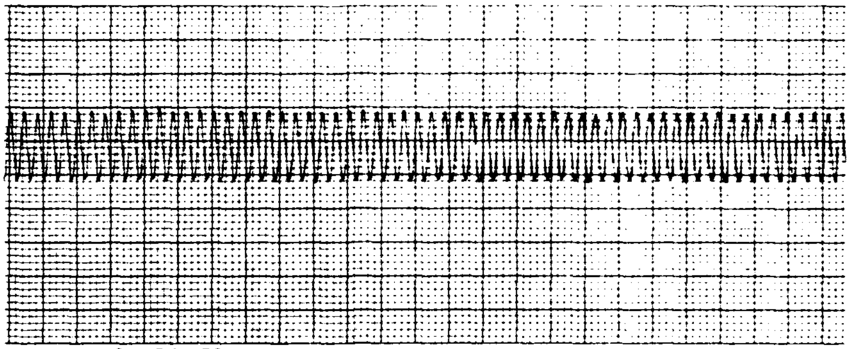


(b) 175 mV noise added

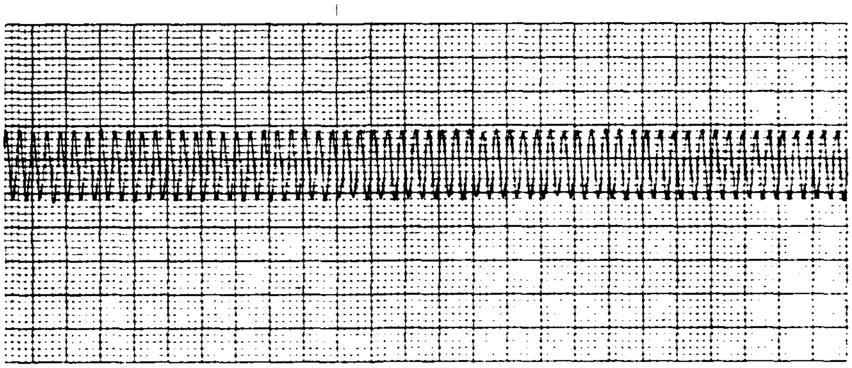


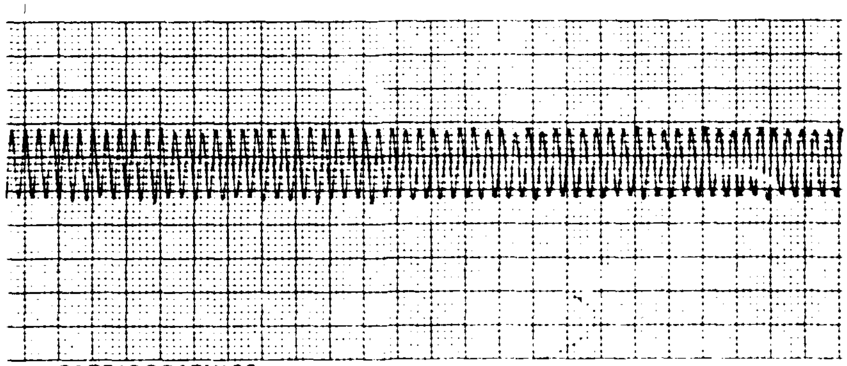
(c) 225 mV noise added

Figure 33. ECG signal traces for receiver sensitivity testing, with 150 mV, 175 mV, and 225 mV rms noise added.



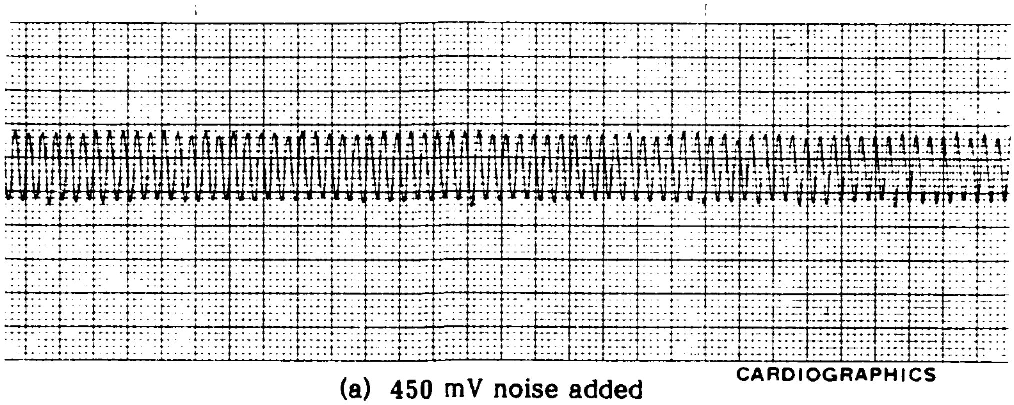
(a) 300 mV noise added


(b) 400 mV noise added

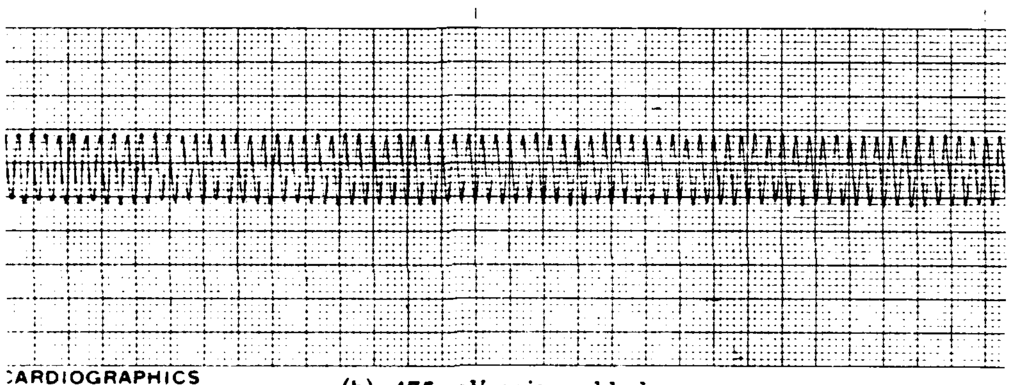


(c) 425 mV noise added

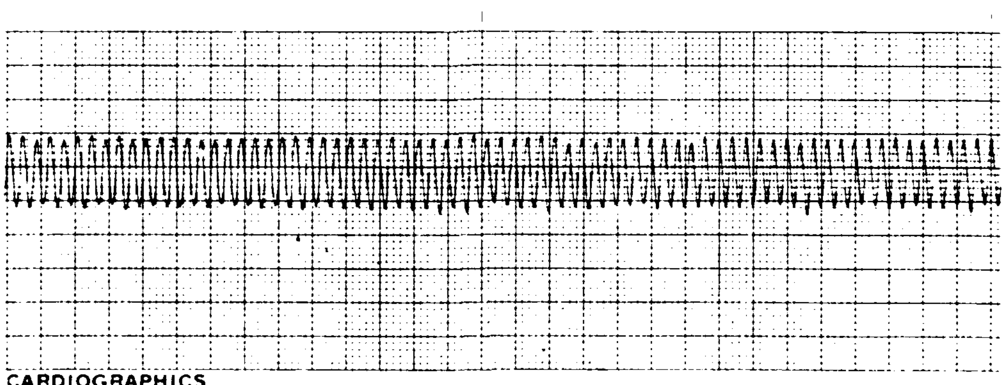
Figure 34. ECG signal traces for receiver sensitivity testing, with 300 mV, 400 mV, and 425 mV rms noise added.



(a) 450 mV noise added



(b) 475 mV noise added



(c) 500 mV noise added

Figure 35. ECG signal traces for receiver sensitivity testing, with 450 mV, 475 mV, and 500 mV rms noise added.

SECTION 4

STETHOSCOPE TESTS

4.1 QUALITATIVE TESTING

Testing was conducted to verify the ability of RMDS terminals to transfer a usable stethoscope signal. A Hewlett-Packard 3960 instrumentation tape recorder was used to record classic pathologic heart sounds from an LP record. The LP record is used as a physician's teaching aid, with a discussion accompanying each heart sound. For testing purposes, only the heart sounds were recorded. At the transmitting terminal, the tape recorder output (PHONE) was patched into the stethoscope input (STETH) via a special straight-through interface patch cord, and the tape recorded heart sounds were transmitted via the RMDS terminals.

Recordings were made of the received stethoscopic sounds via the local and long distance telephone line communication links. These recordings were reviewed by the personnel participating in the testing, who observed a noticeable increase in background noise at the receiving terminal. No value judgment was assigned to the quality of the received recordings, although the stethoscope sounds appeared to be adequate for diagnostic purposes.

Similar testing of the stethoscopic mode was conducted during at-sea testing of the RMDS. The transmitted sounds were reviewed by WVR Vieweg, MD, Head, Cardiology Branch, Naval Regional Medical Center, San Diego. He felt the quality of the transmitted recordings was at the 85th percentile with respect to the record from which the tape was made. However, the quality of the received heart sounds was much poorer, ranked at the 40th percentile level. This indicated a 53% decrease in the quality of recorded heart sound attributable to the RMDS terminals and communication link.

It should be noted that three factors directly contributed to difficulties experienced in diagnosing the stethoscopic heart sounds. First, the number of heartbeats per heart defect was limited to two or three, whereas under normal conditions a physician can listen to a significantly larger number of heartbeats. Second, the transmitted and received recordings contained a large amount of background noise that interfered with heart sounds. A portion of this background noise may be attributed to the RMDS terminals and communication links, whereas a portion may be attributed to the recording process. Any future testing should incorporate procedures to minimize the latter source of noise. Finally, no information was provided as to 1) patient history, 2) physical position of the stethoscope, and 3) additional medical test findings such as ECG, chest X-rays, etc. This lack of this information does not represent a realistic situation; any future testing should take these parameters into account.

4.2 FREQUENCY RESPONSE

Testing was conducted to determine the frequency response of the RMDS terminals for the stethoscope signal transfer mode of operation as a function of input signal amplitude. The test setup used to measure the frequency response for the stethoscope mode of transmission is shown as figure 36. The sine waveform generator output was applied to one channel of an oscilloscope, while the stethoscope output jack from

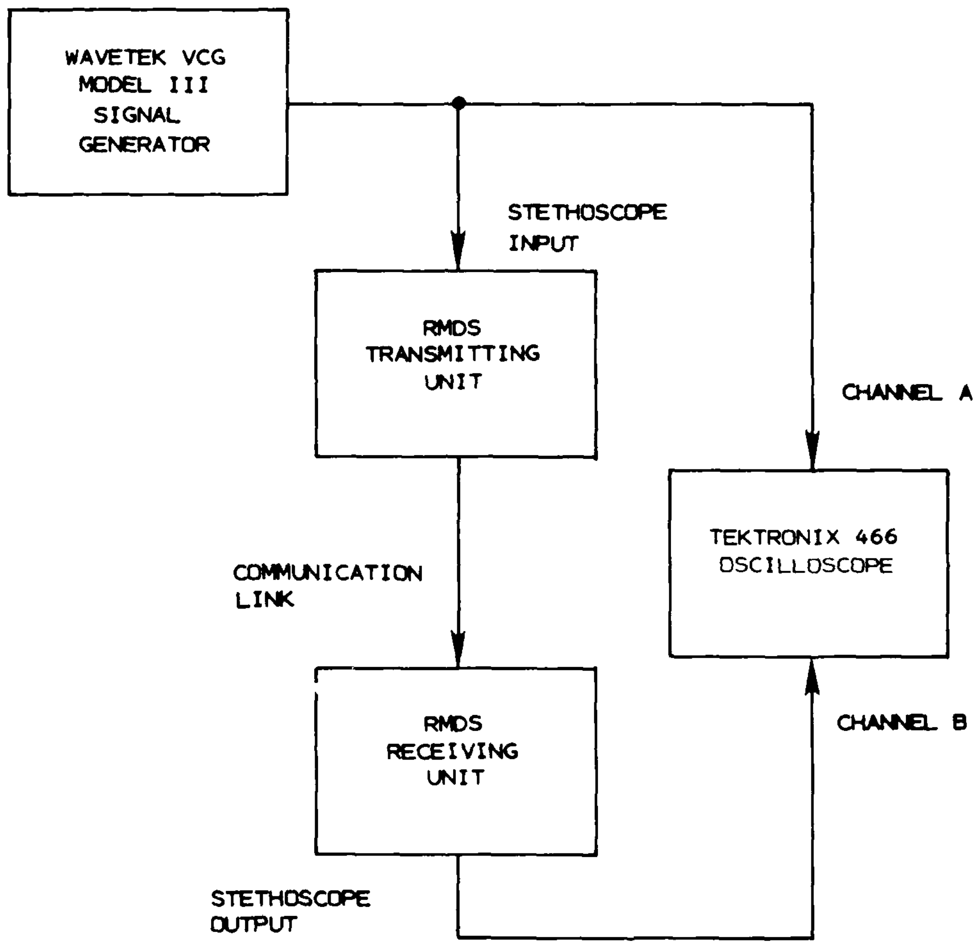


Figure 36. Stethoscope mode frequency response test setup.

the receiving terminal was applied to the second channel of the oscilloscope. In this way a direct comparison could be made of the input and output signal. Voltage levels of 0.5, 0.75, 1.0, and 1.25 volts peak-to-peak (p-p) were monitored, and the above method was used to determine frequency response for various input signal levels. The data obtained in these tests are listed in table 5.

	Received Level (Millivolts p-p)			
Frequency (Hz)	0.5 V p-p Transmitted	0.75 V p-p Transmitted	1.0 V p-p Transmitted	1.25 V p-p Transmitted
1	23.0	31.6	43.5	53.2
2	23.1	33.2	44.5	55.1
4	23.5	34.0	45.0	57.0
10	23.5	34.0	45.0	57.0
20	24.0	34.0	45.0	57.0
50	24.0	34.0	45.0	57.0
100	23.5	34.0	45.0	57.0
200	23.0	33.0	44.0	56.0
400	20.0	30.0	38.0	49.0
800	7.2	10.0	13.5	17.0
1000	3.0	4.0	5.1	6.4
1200	1.8	2.0	2.2	2.6

Table 5. Stethoscope mode frequency response data.

For comparison purposes, the data in table 5 are normalized to 1.0 for each of the input voltage levels; these are plotted in figure 37. All four voltage inputs showed a very similar frequency response over the range of frequencies tested (1-1200 Hz). The flat response portion of the curve lay between 4.0 and 100 Hz. Only the -3 dB point for the higher frequencies could be determined from these data, and it lay roughly at 700 Hz. Previous testing had shown the low frequency -3 dB point to be in approximately the 0.2 Hz region. The response shown by the curves should be more than adequate for heart-lung sound transmission ranging from 15 to 1000 Hz.

4.3 PHASE RESPONSE

Testing was conducted to measure the phase shift of signals transmitted with the RMDS terminals in the stethoscope signal transfer mode of operation. The test setup was similar to the one used in the stethoscope frequency response tests (section 4.2, figure 36), except that only a 1.25 volt peak-to-peak signal was used from the signal generator. This test was run in back-to-back and long distance telephone line communication configurations.

The data obtained from these tests are listed in table 6 and plotted in figures 38 and 39. Figure 38 graphs the data obtained in the back-to-back configuration. The simple linear regression line for the data plotted between 4 and 1000 Hz showed a constant rate of change. This indicated that the phase shift was due to simple delay and that the integrity of the waveform was maintained in transmission. For this line,

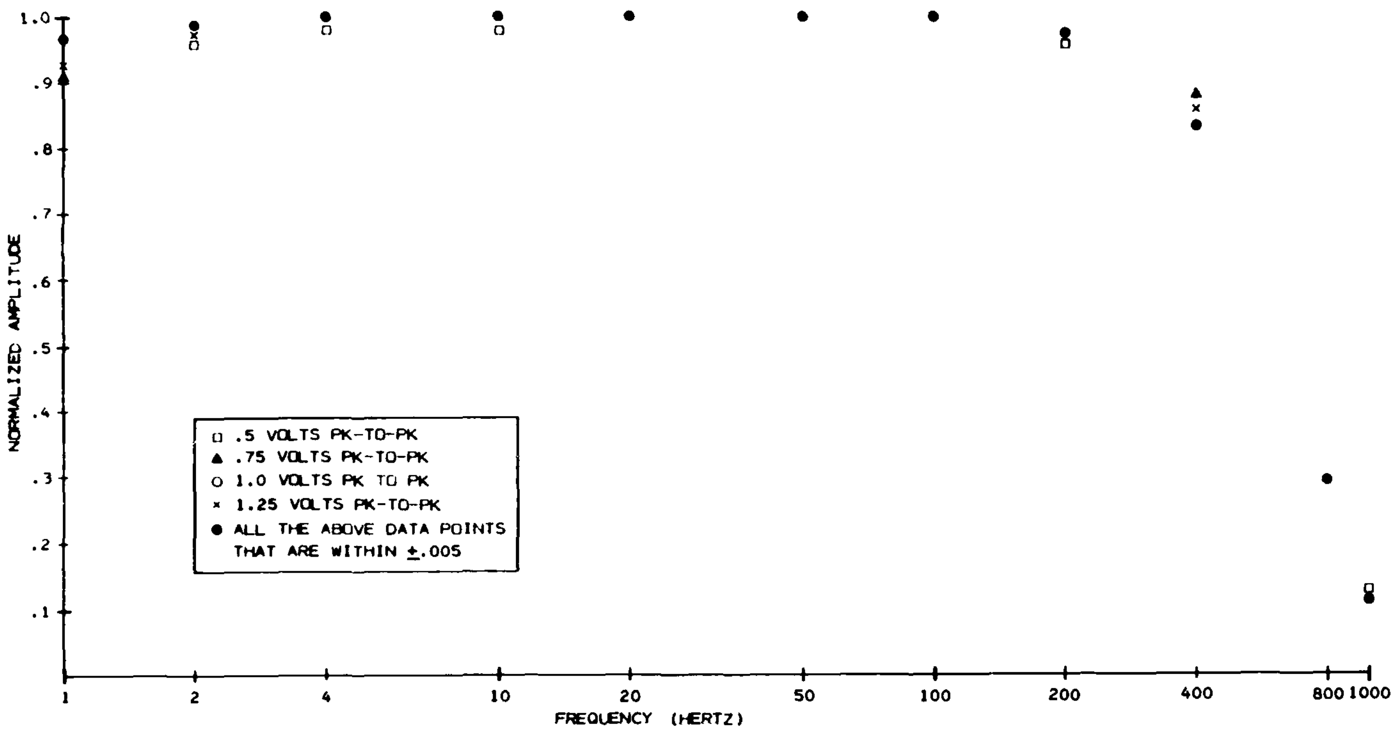


Figure 37. Stethoscope mode frequency response.

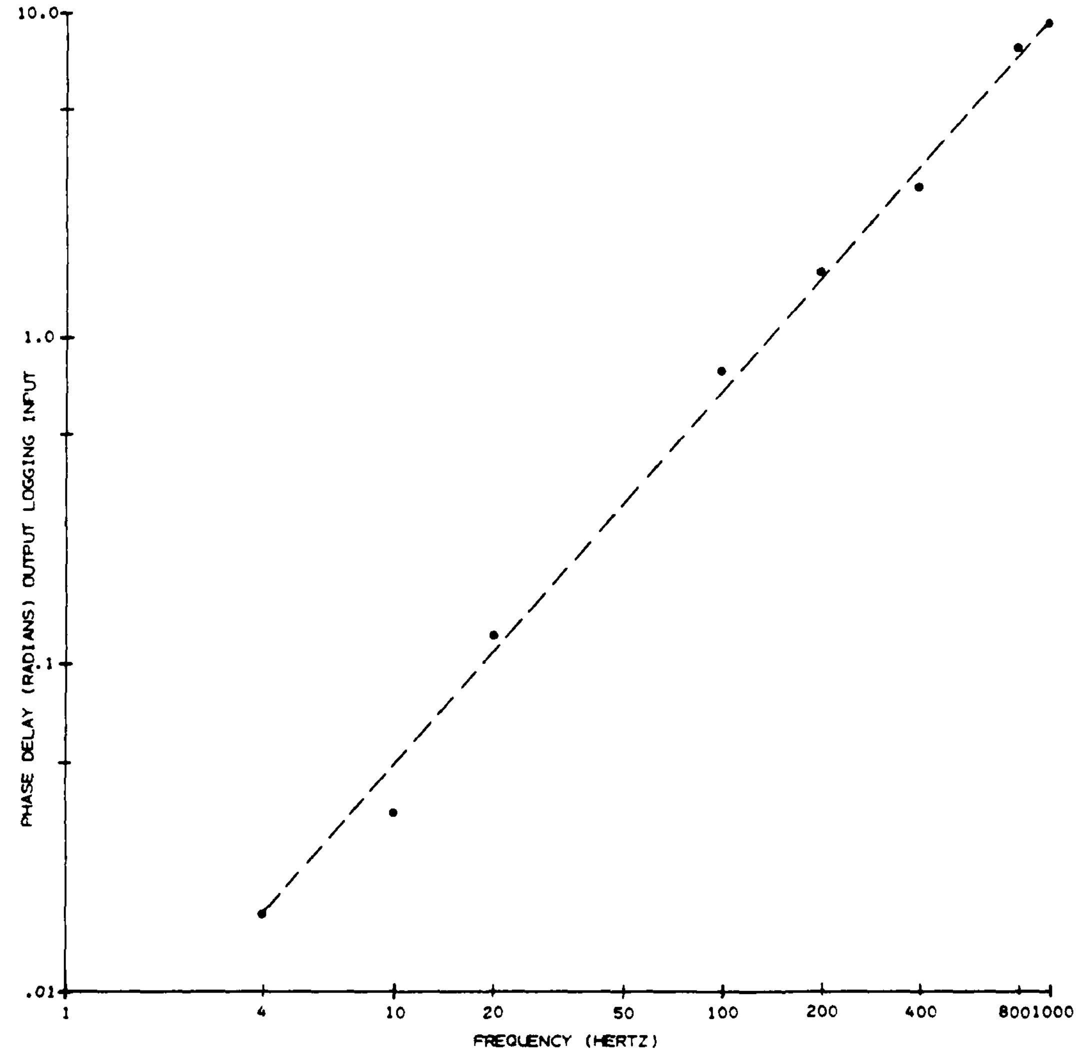


Figure 38. Phase response of stethoscope mode, back-to-back communication link.

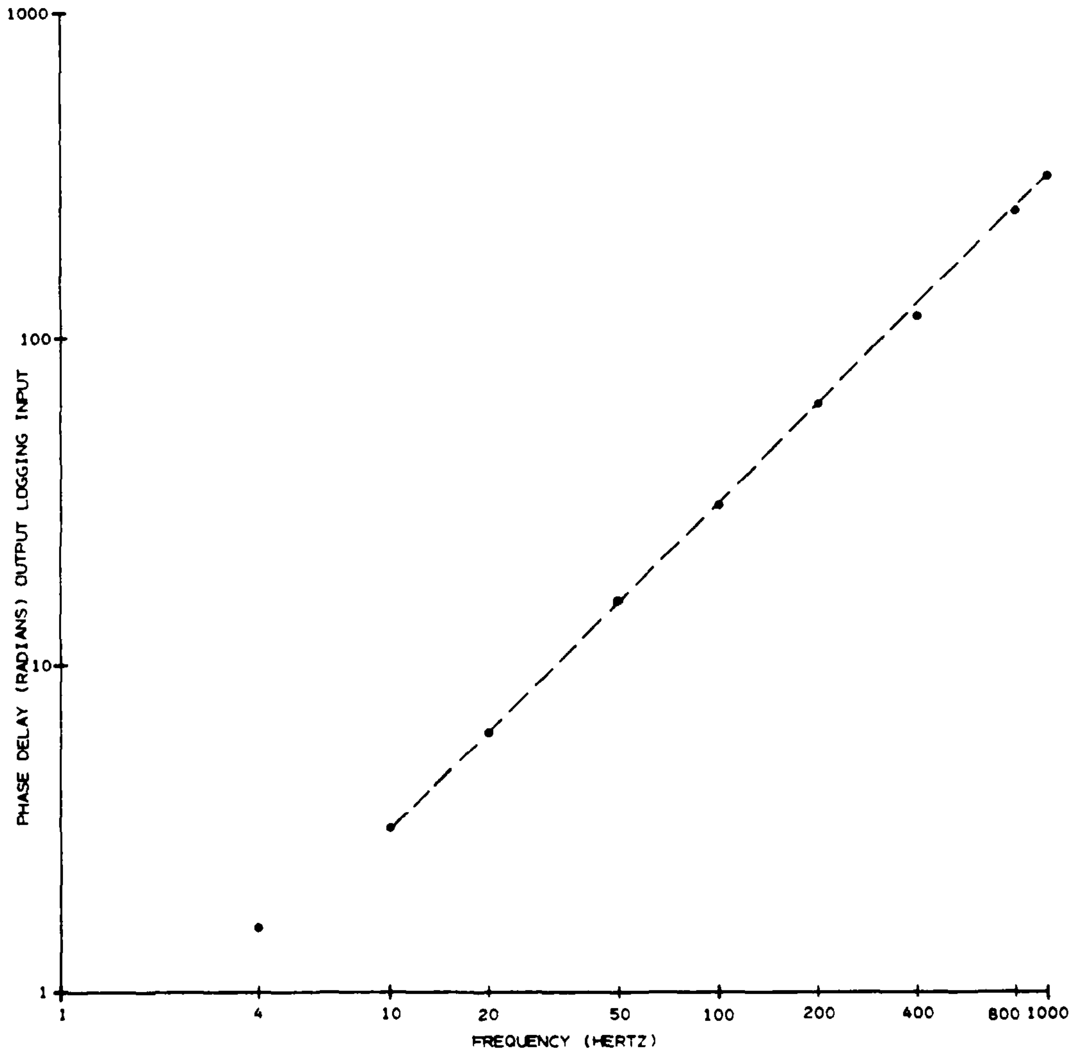


Figure 39. Phase response of stethoscope mode transmission, long distance telephone line communication link.

the time delay was calculated to be 1.6 milliseconds. Figure 39 graphs the data obtained in the long distance telephone line communication link. The measurements of lag for long distance telephone line were relative, because of the magnitude of readings, ie, 1800 to 17,640 degrees lag. The simple linear regression line for the data points between 10 and 1000 Hz showed a constant rate of change. This indicated that phase shift for this form of communication link was also due to simple delay. For this line, the time delay was calculated to be 48.7 milliseconds.

Frequency (Hz)	Back-to-Back		Long Distance Telephone	
	Degrees Lag	Radians	Degrees Lag	Radians
1	0	0.0	0	0.0
2	0	0.0	45	0.79
4	1	0.017	90	1.57
10	2	0.035	180	3.14
20	7	0.122	360	6.28
50	23	0.401	900	15.71
100	45	0.785	1800	31.41
200	93	1.62	3600	62.80
400	167	2.91	6840	119.32
800	450	7.85	14040	245.03

Table 6. Phase response of stethoscope mode transmission.

4.4 HARMONIC DISTORTION

Testing was performed to measure the distortion of a 500 Hz signal transmitted between RMDS terminals by the stethoscope signal transmission mode. The RMDS terminals were connected with back-to-back, local telephone line, and long distance telephone line communication links. The setup for this test is shown in figure 40. An audio frequency signal generator was used to supply a 0.3 volt RMS, 500 Hz signal to the transmitting terminal at the STETH jack. A distortion analyzer was used to measure the output at the receiving terminal's STETH jack. The signal generator was pretested for harmonic distortion, and it possessed only 0.35% total harmonic distortion. Harmonic distortion above this level in the received signal was assumed to be due to the RMDS terminals and the communication link.

The values obtained for total harmonic distortion, including noise, were as follows:

Communication Link	Percent Harmonic Distortion (including noise contribution)
Back-to-Back	3.0 percent
Local Telephone Line	2.6 percent
Long Distance Telephone Line	14.0 percent

A noticeable increase in harmonic distortion was observed for long distance telephone line communication links. It should be noted that frequency-dependent amplitude attenuation and delay distortion are typical of unconditioned telephone line

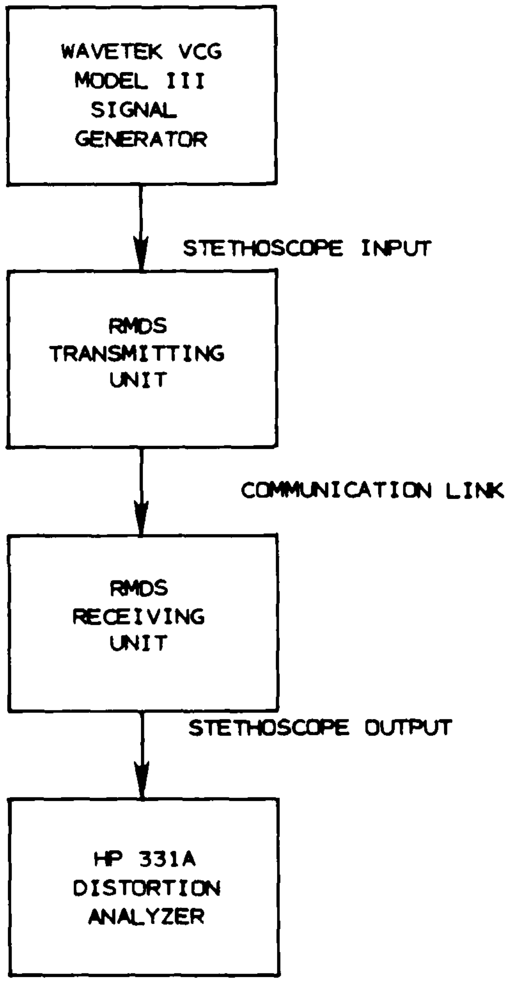


Figure 40. Stethoscope harmonic distortion measurement test setup.

transmission, with delay distortion increasing with distance. For the tests reported herein, this had the effect of distorting the spectral content of a transmitted signal nonuniformly, thereby resulting in harmonic distortion of the received signal that would become increasingly worse over longer distance transmission.

4.5 NOISE LEVEL

Testing was conducted to measure the received noise levels for the RMDS terminals and the communications links when operating in the stethoscope signal mode. The test setup and procedure was similar to the testing for noise level in ECG mode (see section 3.4, figure 27), except that a shorted plug was attached to the STETH input jack of the transmitting terminal and measurements were taken at the receive terminal STETH jack.

Original Testing

The same ambient levels of rf noise observed in the ECG noise testing were present during this test, ie, a randomly occurring 1.5-2.0 volt peak-to-peak noise spike, a 1 MHz communication signal, and 60 Hz random noise. Again, a termination capacitor and load resistor were shunted across the oscilloscope input to aid in measurements. The RMS noise levels obtained for the conditions tested were as follows:

Communication Link	RMS Noise Level
Back-to-Back	7.5 mV
Local Telephone Line	45.0 mV
Long Distance Telephone Line	50.0 mV

These measurements showed a general trend of increasing noise levels with increasing complexity of the communication link. This is very typical of random noise levels on telephone lines, as indicated below.

Levels and SNRs on Voice-Grade Lines

	On Leased Telephone Lines	On DOD Network Local Area	Long Distance
Transmit Level	0 dBm	-2 to -10 dBm*	-2 to -10 dBm*
Receive Level	-12 to -20 dBm	-16 to -30 dBm	-24 to -32 dBm
Line Loss (typical)	16 dBm	16 dBm	20 to 25 dBm
Typical Noise Level	-50 to -65 dBm	-50 to -65 dBm	-48 to -60 dBm
Typical SNR	36 dB	34 dB	28 dB
Minimum SNR Specified	24 dB	None	None

Comparing these noise levels to a stethoscope signal referenced to 1.0 volt showed that even under the poorest condition tested (long distance telephone), the noise level represented only 5% of the signal, or a signal-to-noise ratio of 26.0 dB. This indicated

*In most cases the level of the transmit signal input to a data coupler ranges from -3 dBm to -8 dBm.

that the RMDS was capable of stethoscope transmission with typical telephone noise levels, resulting in no noticeable received signal degradation.

Laboratory Retesting

High ambient levels of rf and 60 Hz noise generated some doubt as to the reliability of the original RMDS noise measurements (see section 3.4, Original Testing). In an attempt to validate the original noise measurements, all RMDS noise testing was repeated during the laboratory retesting period. During the laboratory retesting period high ambient levels of rf and 60 Hz noise were again found to exist at the NOSC facility and steps were taken to reduce their effect on testing (see section 3.4, Laboratory Retesting). Stethoscopic noise measurements were recorded as received RMS noise by means of a dual-trace oscilloscope procedure. Listed below are the values obtained during the laboratory retesting period:

	RMS Noise (mV)	
Communication Link	Live	Tape Playback
Back-to-Back	24	100
Local Telephone Line	13	90
Long Distance Telephone Line	12*	140**

*200 mV periodic burst
**300 mV periodic burst

The noise measurements obtained for the various live communication links were comparable to the original testing measurements. The noise levels for back-to-back communications (24 mV) represented a signal-to-noise ratio of 32.4 dB when referenced to a 1.0 volt signal. This indicated that the RMDS was capable of stethoscope transmission with typical telephone noise levels, resulting in no noticeable received signal degradation.

Noise levels obtained for stethoscopic transmissions in conjunction with the tape recorder playback were substantially higher than stethoscopic live and ECG tape playback noise levels. The utility of tape recorder playback is questionable since noise levels of 100 mV (back-to-back) represent a signal-to-noise ratio of 20.0 dB when referenced to a 1.0 volt signal.

SECTION 5

VIDEO TESTS

The CGM Model 113T TV camera procured for the RMDS terminals was used for video testing during the original laboratory test period. Various aspects of the RMDS video system were retested to determine the effects of upgrading the camera system. For retesting, a Cohu Model 7120 TV camera was used. Listed below are the video tests performed with the Cohu TV camera:

- Horizontal Resolution
- Signal-to-Noise Level
- Gray Scale

Two additional tests were performed during the retesting period by means of the CGM camera:

- Signal-to-Noise Levels
- Vertical Resolution

CGM signal-to-noise level retesting was performed to validate the data obtained during the original testing period. Vertical resolution tests were not performed during the original laboratory testing period, since a particular item of test equipment was lacking (Colorado Video, Inc. Model 321 Video Analyzer). Acquisition of this test equipment permitted vertical resolution measurement during the laboratory retesting period.

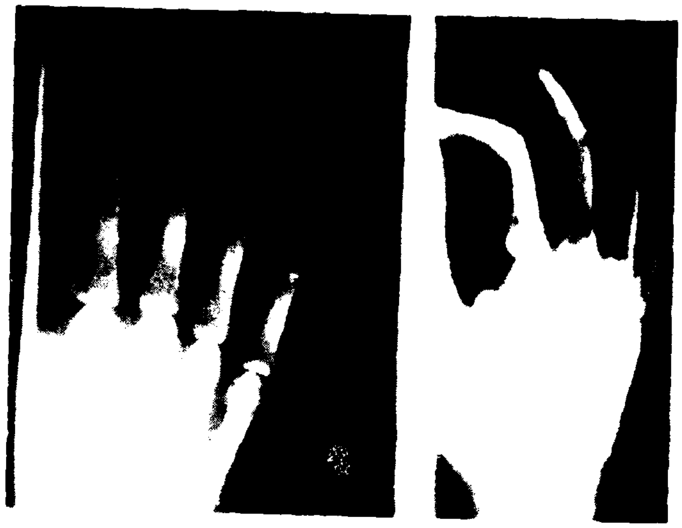
5.1 QUALITATIVE TESTING

Original Testing

Testing was conducted to determine the subjective quality of images transferred via the RMDS terminals (CGM TV camera). Comparisons were made between:

- Communication links
- Analog and digital transmission
- Coarse and fine resolution
- Remote and main camera

At the receiving terminal, photographs were taken of the images transmitted. Representative samples are shown as figures 41 through 52. (Figures 41 through 43 are photographs of an X-ray used for image transmission, and figures 44 through 52 are photographs of test patterns.)



(a) Digital, fine

(b) Analog, fine

Figure 41. Received image of hand X-ray, main camera, analog and digital transmission, back-to-back.

(a) Digital, fine

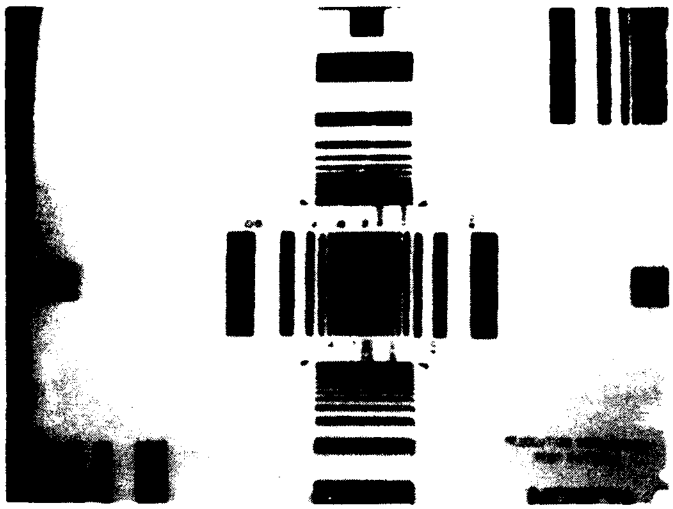
(b) Analog, fine

Figure 42. Received image of hand X-ray, main camera, analog and digital transmission, local telephone.

(a) Digital, fine

(b) Analog, fine

Figure 43. Received image of hand X-ray, main camera, analog and digital transmission, long distance telephone.



(a) Digital, fine

(b) Analog, fine

Figure 44. Received image of test pattern, main camera, analog and digital transmission, back-to-back.

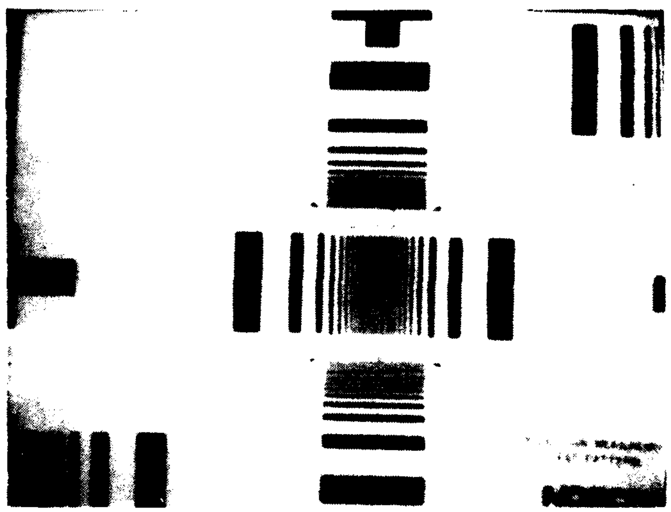
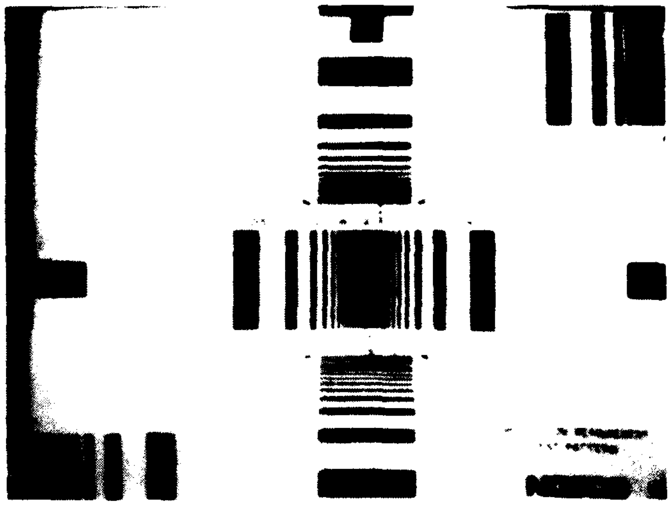
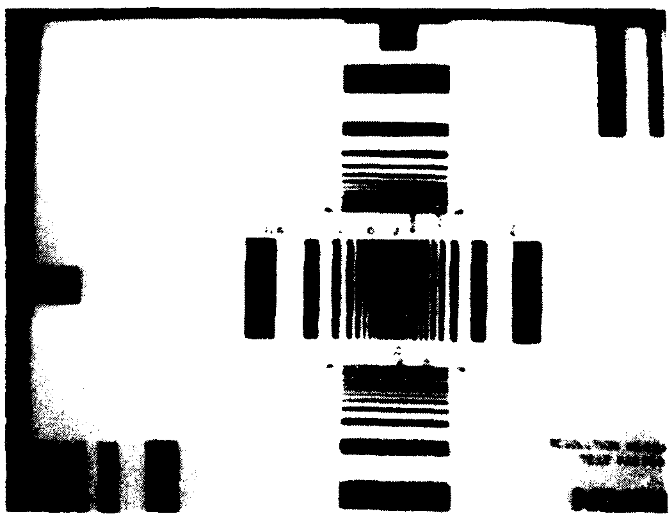


Figure 45. Received image of test pattern, main camera, analog and digital transmission, local telephone.



(a) Fine



(b) Coarse

Figure 46. Received image of test pattern, main camera, digital transmission, local telephone.

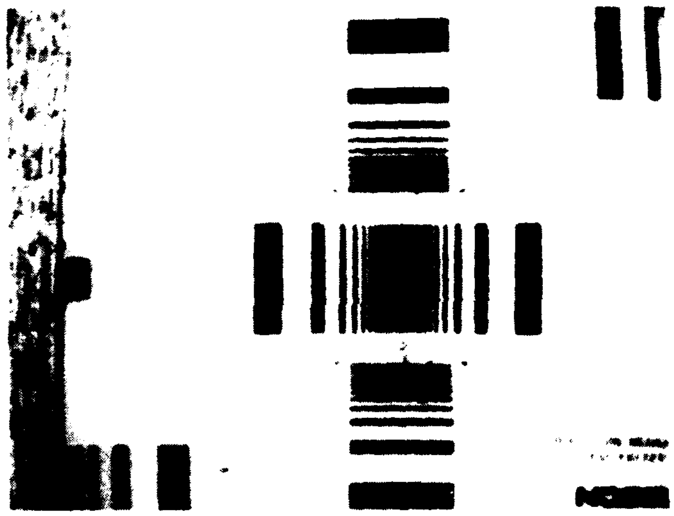
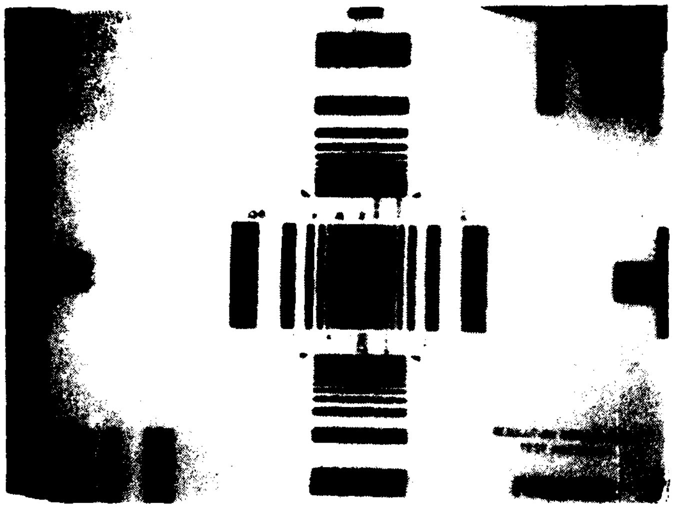
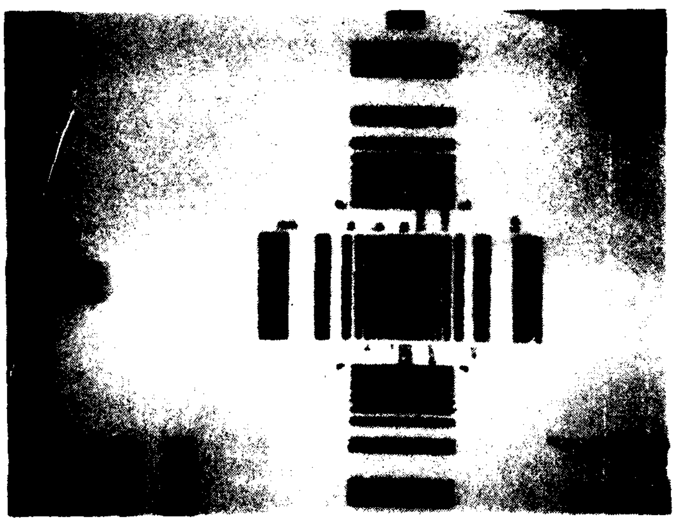


Figure 47. Received image of test pattern, main camera, fine, analog transmission, long distance telephone.

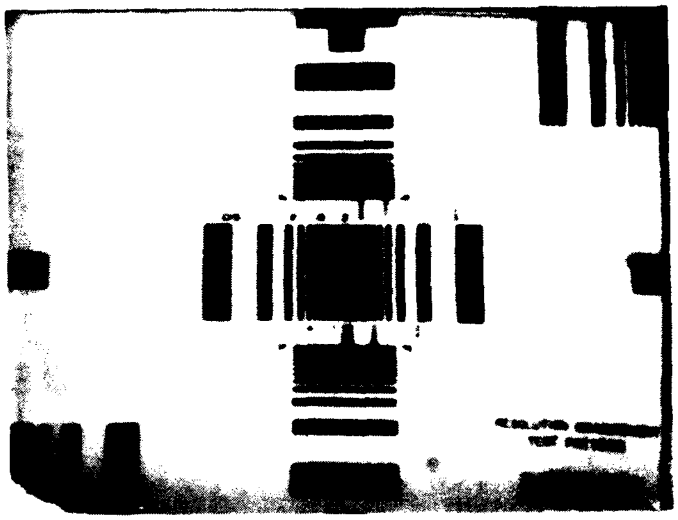


(a) Fine

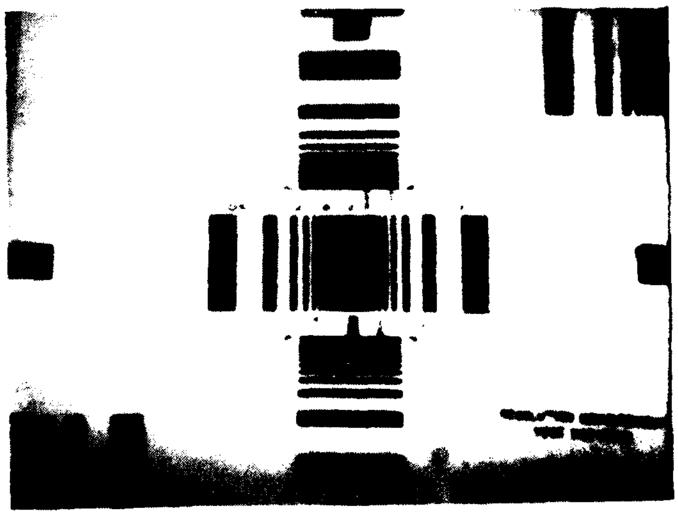


(b) Coarse

Figure 48. Received image of test pattern, main camera, digital transmission, long distance telephone.

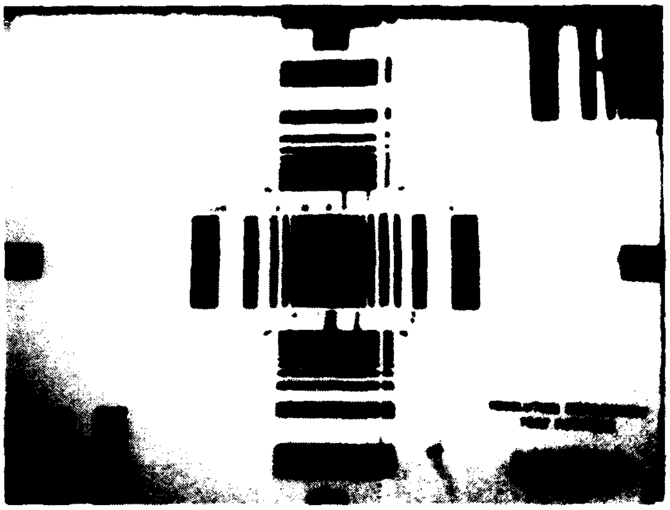


(a) Digital, fine

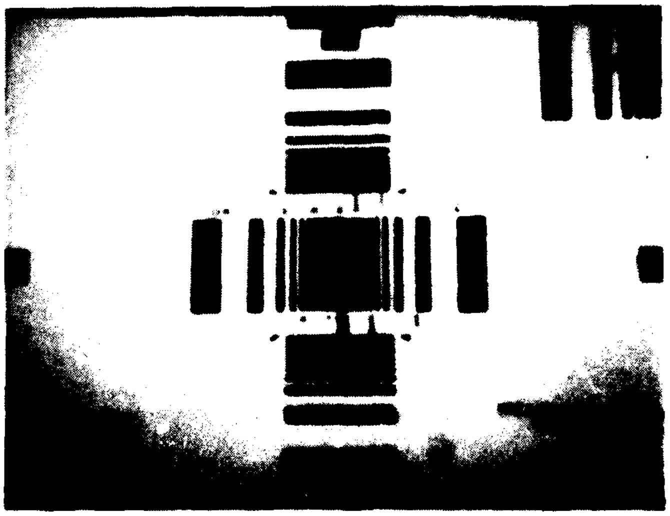


(b) Analog, fine

Figure 49. Received image of test pattern, remote camera, analog and digital transmission, back-to-back.

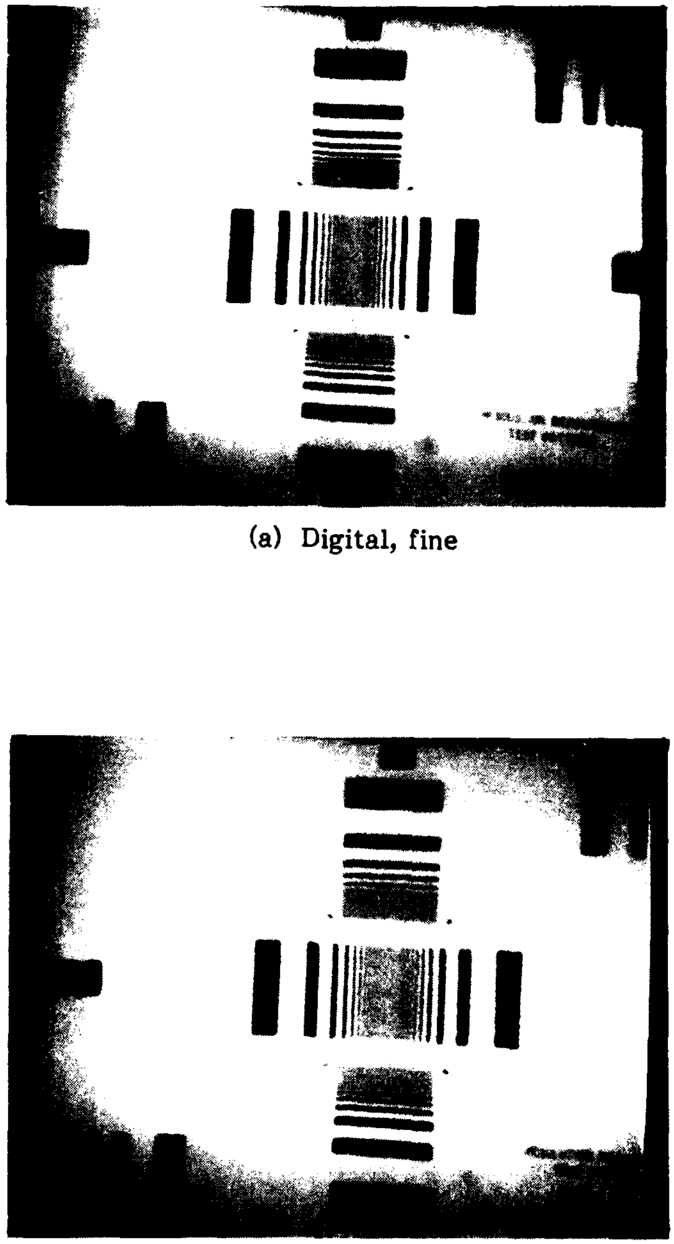


(a) Digital, fine



(b) Analog, fine

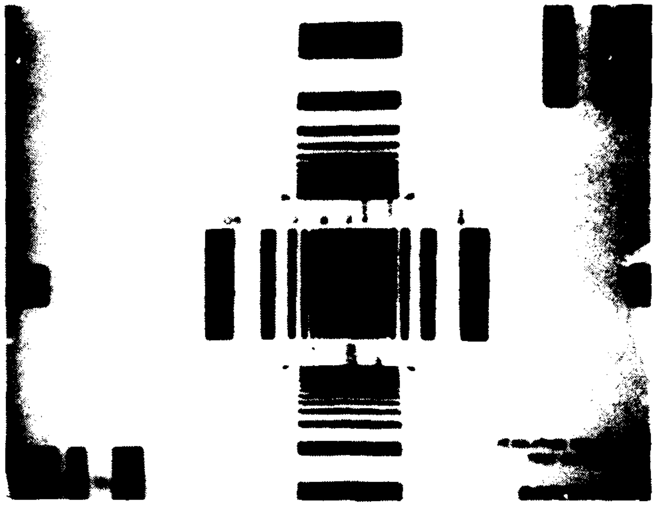
Figure 50. Received image of test pattern, remote camera, analog and digital transmission, local telephone.



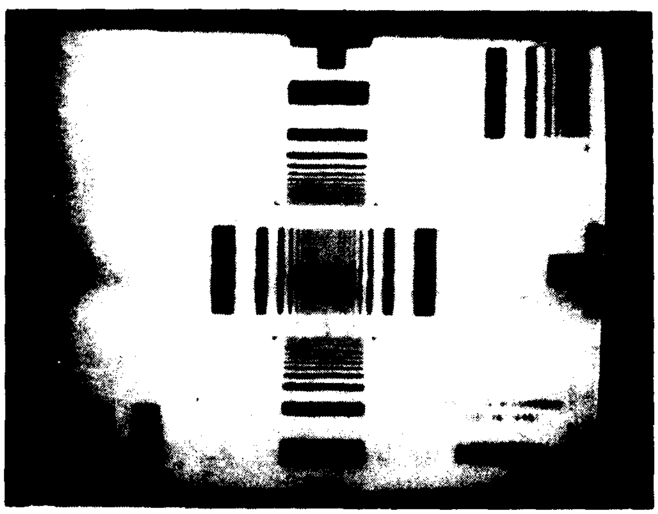
(a) Digital, fine

(b) Analog, fine

Figure 51. Received image of test pattern, remote camera, analog and digital transmission, long distance telephone.



(a) hf



(b) uhf/satellite

Figure 52. Received image of test pattern, digital fine transmission, hf and uhf/satellite.

In general the quality of the images received was good, with only slight differences between the conditions tested. Quality of the images tended to decrease slightly as the test conditions changed from 1) back-to-back to local to long distance telephone, 2) digital to analog, 3) fine to coarse, and 4) uhf/satellite to hf. The images transmitted by the remote camera (figures 49, 50, and 51) were very similar to those transmitted by the main camera. It should be noted that the reproduction copies of the photographed images do not show the slight differences seen between test conditions.

A comparison of the analog versus digital photographs with a back-to-back communication link (figure 44) showed a noticeable increase in quality for the digital mode. The digital mode of transmission had better detail than analog, with sharper edges for black-to-white transitions. An increase in quality for the digital mode is clearly seen in the long distance telephone line communication link by comparing figure 47 to figure 48.

A comparison of digital coarse versus fine over local and long distance telephone line communication links is shown in figures 46 and 48. Figure 48 shows a moiré effect beginning at 0.4 line pairs per mm of horizontal resolution for coarse and 0.5 line pairs per mm of horizontal resolution for fine. This indicated an increase in horizontal resolution for the fine mode of transmission.

Figure 52 shows representative photographs for hf and uhf/satellite communication links. The quality of the received images for these links was good, with each having 0.5 line pairs per mm of horizontal resolution visible on test pattern.

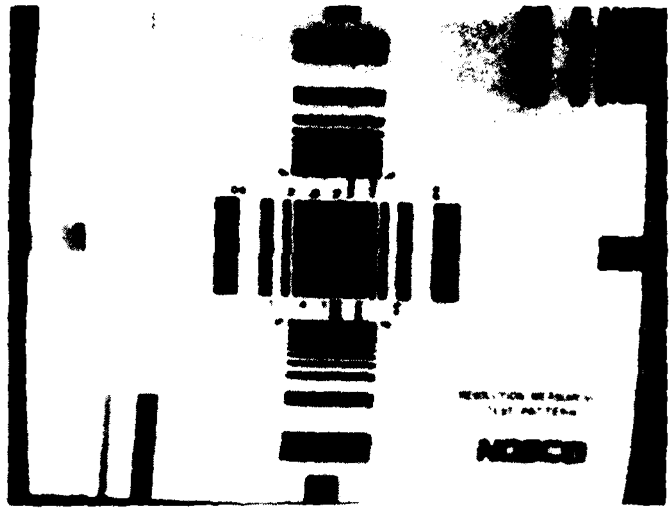
During testing of the hf communication link, rf burst noise distorted image reception and retransmission of the image was required. Hf image transmission was also susceptible to interference from nearby hf frequencies. Rf burst noise was present during uhf/satellite communication link testing to a lesser degree, and noise in the form of vertical black and white lines would appear in the received image. Occasionally, retransmission of the image was required during uhf/satellite transmission. It should be noted that uhf/satellite transmission and reception involves encryption and decryption of transmitted data. The necessity to retransmit images received via uhf/satellite communication links was believed to be caused by the loss of crypto sync during transmission/reception.

Laboratory Retesting

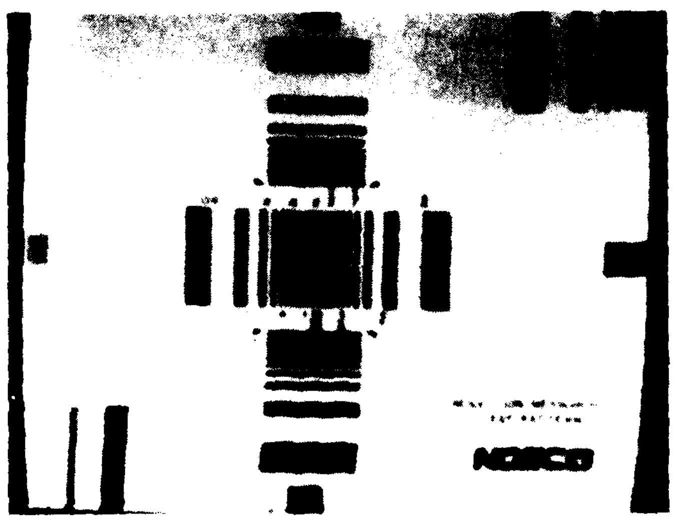
Testing was conducted to determine the subjective quality of images transferred via the Cohu TV camera system RMDS terminals. Comparisons were made between:

- Communication links
- Analog and digital transmission
- TV Camera system used (Cohu vs CGM)

Photographs were taken of the images received. Representative samples are shown as figures 53 through 55.

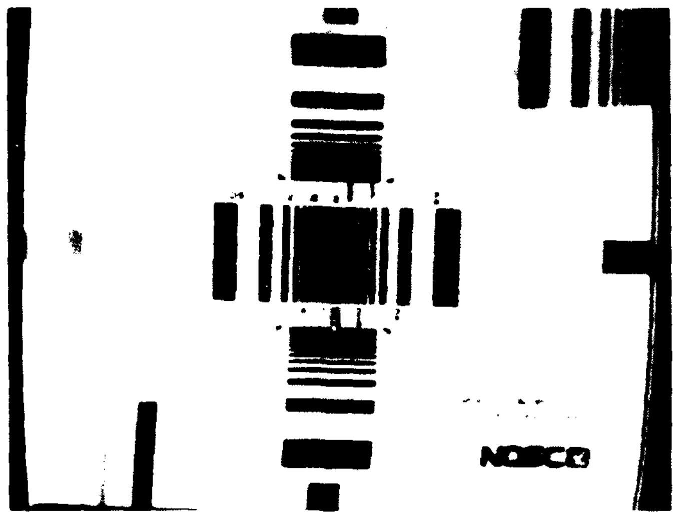


(a) Digital, fine

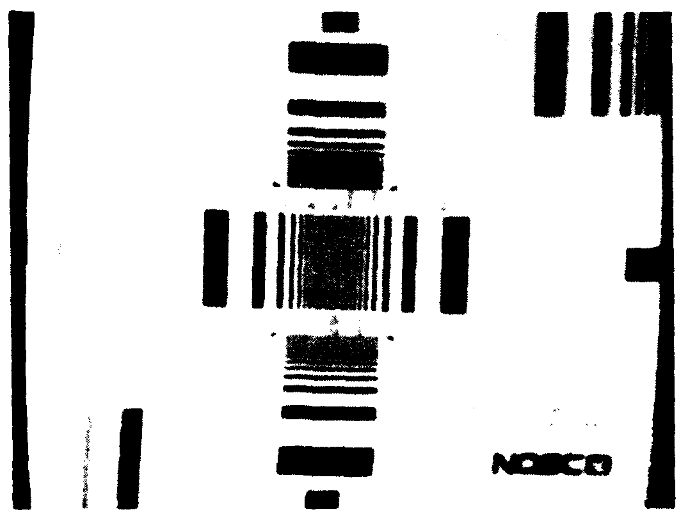


(b) Analog, fine

Figure 53. Received image of test pattern, Cohu camera, analog and digital transmission, back-to-back.

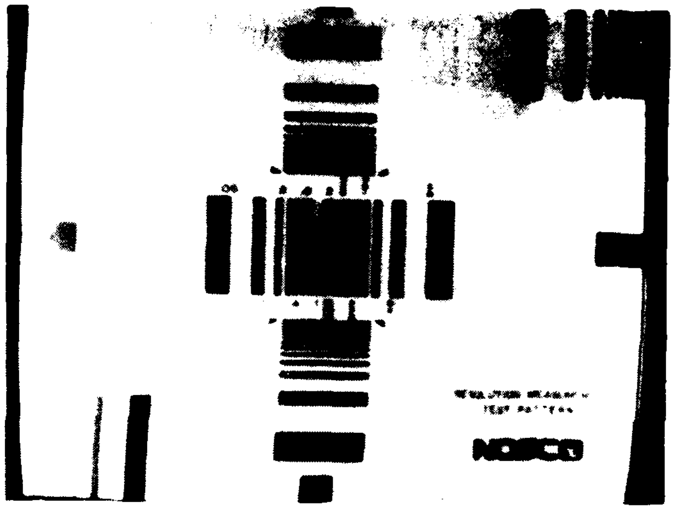


(a) Digital, fine

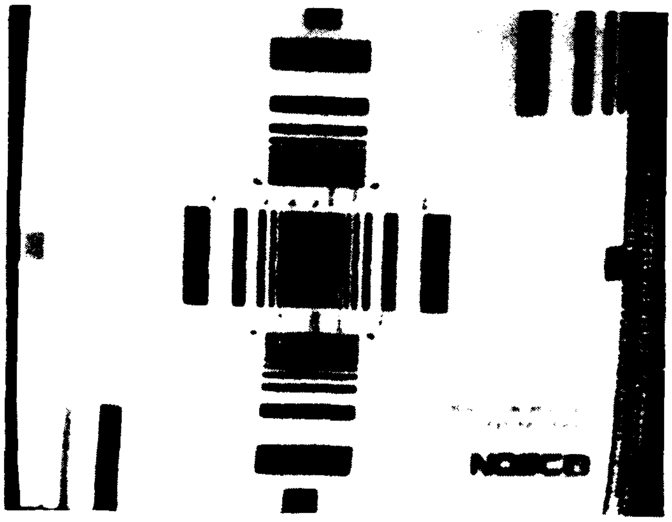


(b) Analog, fine

Figure 54. Received image of test pattern, Cohu camera, analog and digital transmission, local telephone.



(a) Digital, fine



(b) Analog, fine

Figure 55. Received image of test pattern, Cohu camera, analog and digital transmission, long distance telephone.

As in the original testing period, the quality of the images received was good, with only slight differences between the conditions tested. Quality of the images tended to decrease slightly as the test conditions changed from 1) back-to-back to local to long distance telephone line communication links and 2) digital to analog transmission modes.

A comparison of the photographs shown in figures 44 through 48 (CGM) with figures 53 through 55 (Cohu) showed no noticeable increase in quality for the images received on the Cohu camera. This indicated that increases in camera capabilities alone will not improve RMDS video quality.

5.2 VIEWBOX LIGHTING UNIFORMITY

Testing was conducted to determine the uniformity of the light being emitted throughout the surface of the viewbox. With the viewbox energized, light measurements were taken with a Gamma Scientific T500 Telephotometer on the surface of the viewbox at positions corresponding to those given in figure 56. The height of the probe was fixed such that the probe viewed an area of approximately one square inch. Care was taken to insure that no extraneous light, either direct or reflected, entered the photometer probe.

Table 7 lists the measured values of light corresponding to the positions on figure 56 in footlamberts, normalized to 65 footlamberts. Shown are the largest measurements obtained.

Figure 57 shows a plot of the normalized light measurements in the horizontal and vertical directions with respect to the center of the viewbox. The luminance of the viewbox decreased noticeably the farther one moved from the center, with an average decrease in luminance of 37% at the edges. The right half of the viewbox decreased at a faster rate than the left, with the largest decrease in luminance occurring in the lower right corner, which showed an 85% decrease compared to the center of the viewbox. The effect of poor lighting uniformity of the viewbox was to decrease the image signal level for the peripheral portions of large radiographs, with a potential decrease in diagnostic accuracy in these areas. To aid in image transmission quality and avoid having to reposition video material to areas of better lighting uniformity, an effort should be made to achieve a more even lighting level over the surface of the viewbox.

5.3 HORIZONTAL RESOLUTION MEASUREMENT

Testing was conducted during the original and laboratory retesting period to determine the horizontal resolution of the video system elements under various conditions. Although variations in test conditions existed between the two testing [illegible] the same test procedure was utilized. First, the TV camera was adjusted [illegible] the Resolution Measurement Test Pattern shown in figure 58. The camera [illegible] so that the 7-1/2 x 10 inch field of the test pattern just filled [illegible] imaged by the TV camera. Next, the focus and brightness controls [illegible] adjusted to produce a visually optimum image display. [illegible] attached at the appropriate point to monitor the video signal [illegible] was displayed (figure 58). This line of video was expanded [illegible] until the signal representing just the left half of [illegible]

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REMOTE MEDICAL DIAGNOSIS SYSTEM (RMDS) ADVANCED DEVELOPMENT MOD--ETC(U)
JAN 82 W T RASMUSSEN, I STEVENS, P D HAYES N66001-78-C-0274
UNCLASSIFIED NOSC-TR-691 NL

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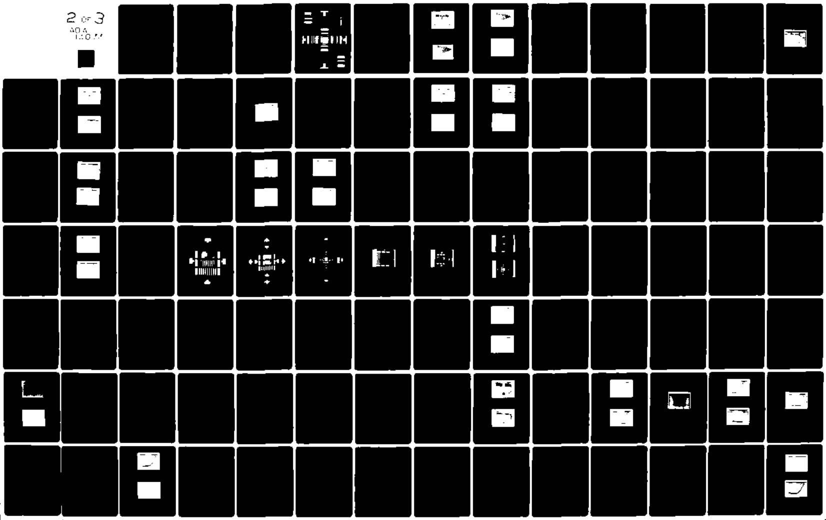


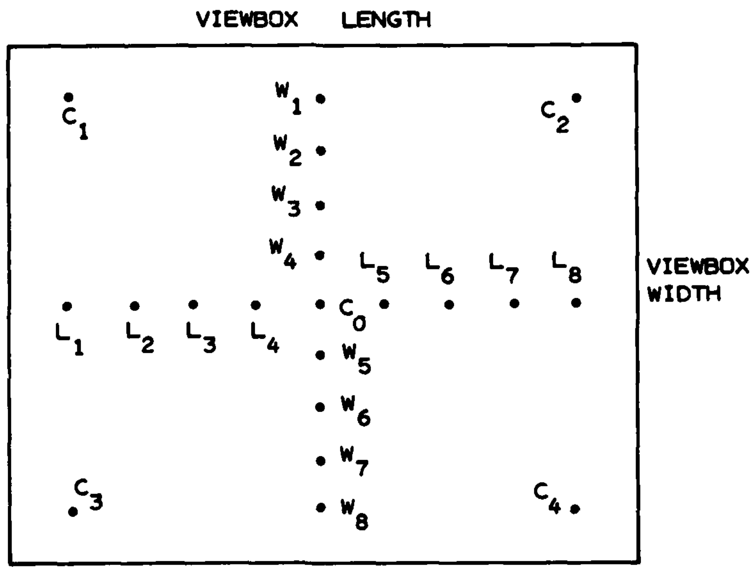


Figure 56. Test positions for viewbox lighting uniformity tests.

	Measured Light Values	
Position	Footlamberts	Normalized
L_1	50	0.75
L_2	55	0.85
L_3	60	0.92
L_4	65	1.00
L_5	65	1.00
L_6	60	0.92
L_7	50	0.77
L_8	45	0.69
W_1	60	0.92
W_2	65	1.00
W_3	65	1.00
W_4	65	1.00
W_5	65	1.00
W_6	60	0.92
W_7	55	0.85
W_8	50	0.77
C_0	65	1.00
C_1	45	0.69
C_2	35	0.54
C_3	35	0.54
C_4	10	0.15

Table 7. Viewbox lighting uniformity measurements (corresponding to the positions given in figure 56).

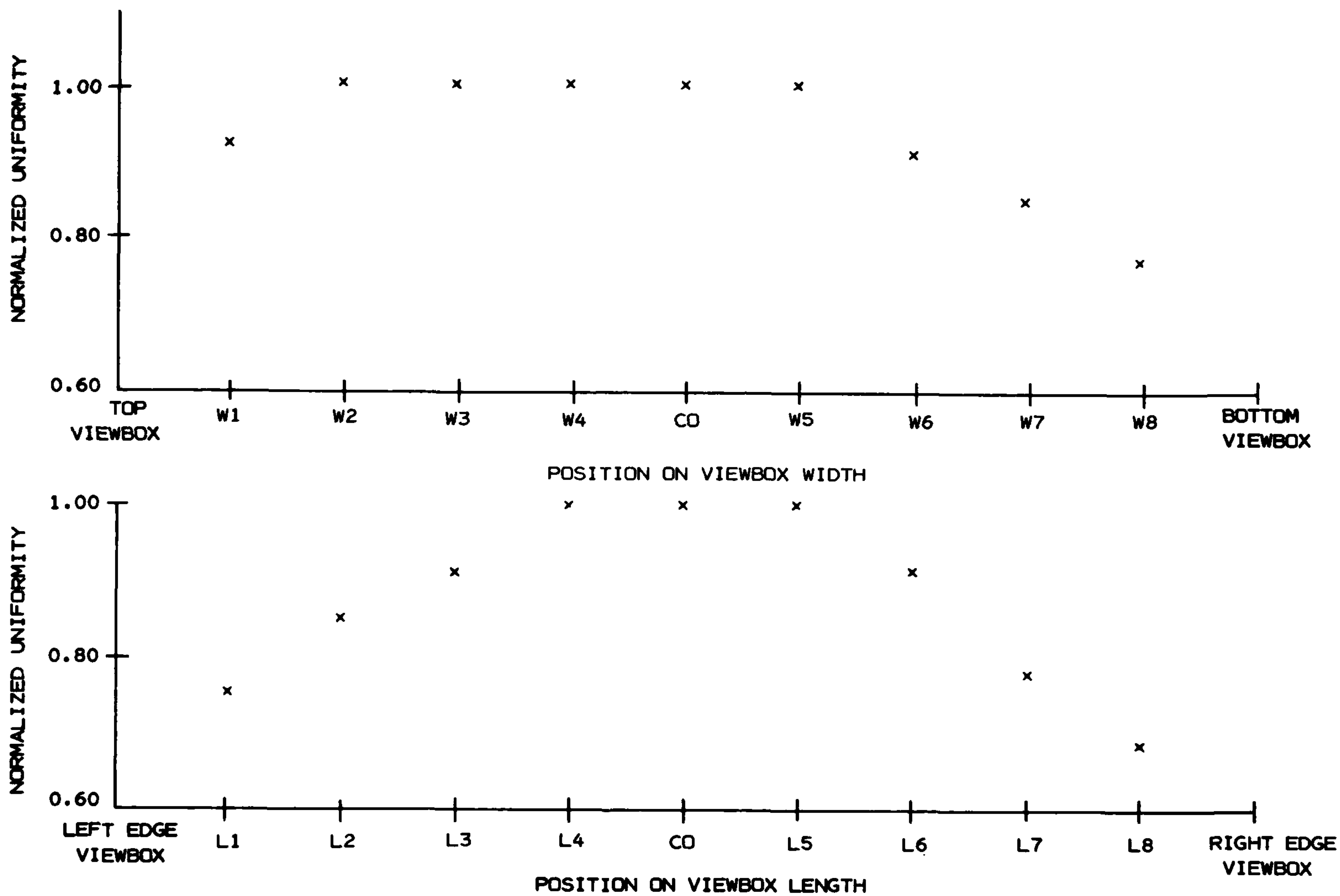


Figure 57. Viewbox lighting uniformity - photometer response for positions along width and length of viewbox.

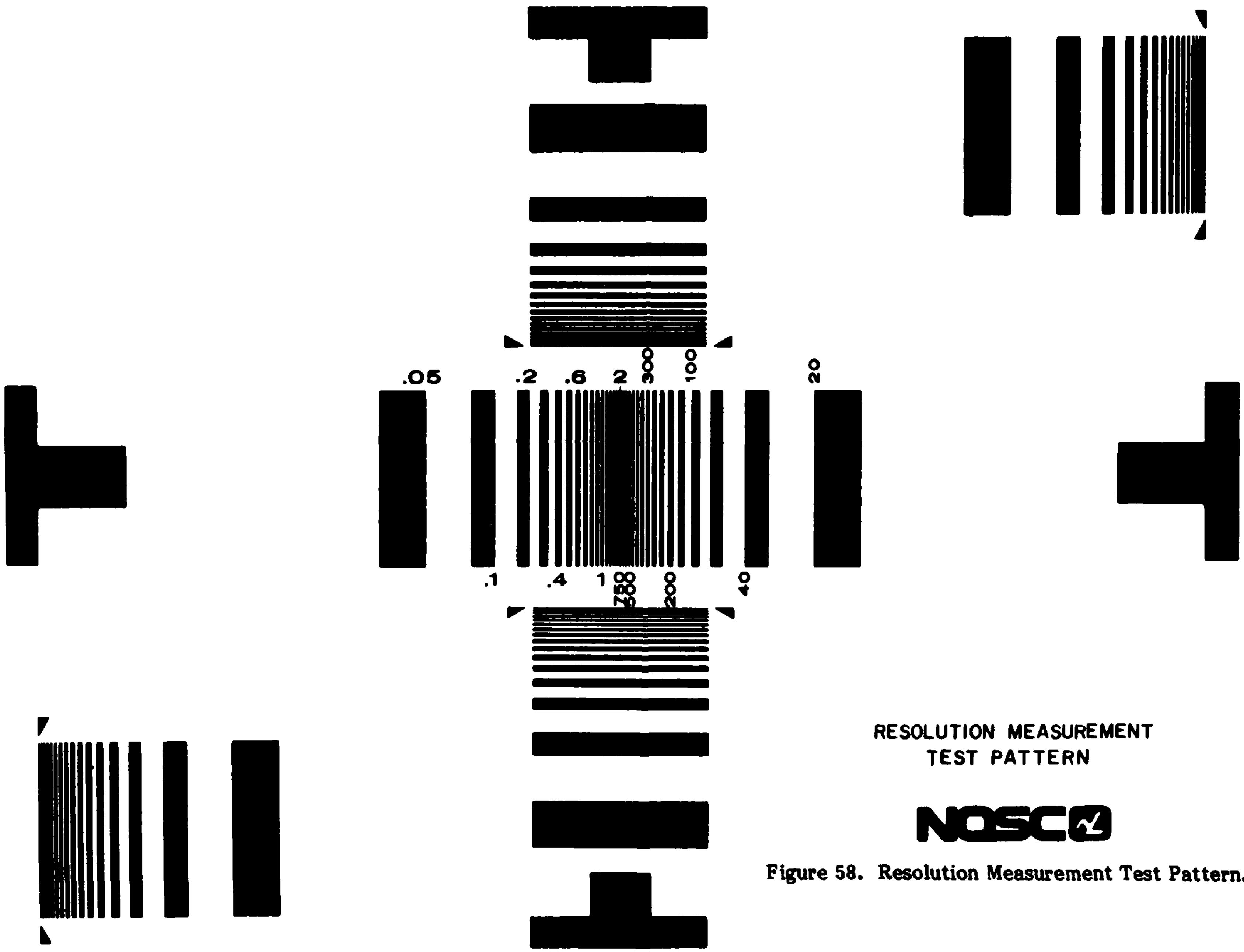


Figure 58. Resolution Measurement Test Pattern.

adequate setup was developed for the display of the single horizontal line of the video signal, the oscilloscope display was photographed by a Polaroid camera. The peak-to-peak waveform height for each cycle of the pattern was then measured from the photograph. The data were normalized to the peak-to-peak amplitude versus the spatial frequency for the corresponding cycles, resulting in a normalized square wave amplitude response curve. This was approximately equivalent to the modulation transfer function curve for the system being tested.

5.3.1 TV Camera/Lens System

Original Testing

The CGM TV camera was tested for center and corner field response under the following conditions:

- 24-1/2" pattern-to-lens distance
- 24-1/2" pattern-to-lens distance with a 1.0 optical density filter
- 30" pattern-to-lens distance

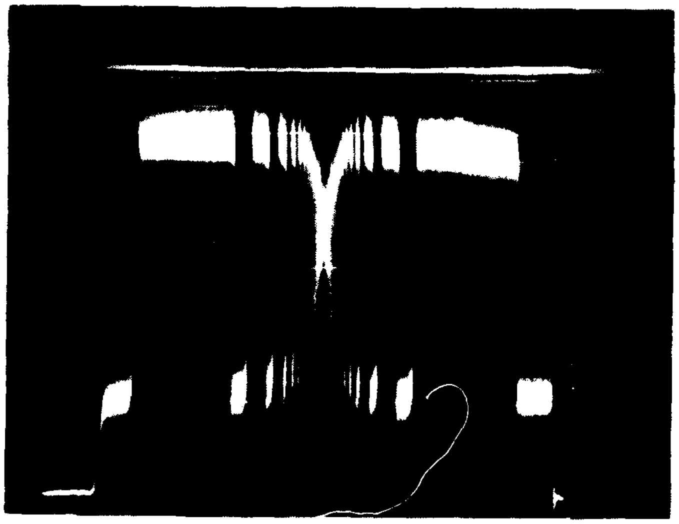
Figures 59 and 60 are representative samples of the photographs taken from the oscilloscope. Tables 8 and 9 give the recorded measurements of peak-to-peak normalized amplitude versus line pair spatial frequency for all conditions tested. The data of table 8 are plotted in figure 61 for the center field response information, and the data of table 9 are plotted in figure 62 for the lower left corner field response.

Figure 61 (center field response) shows similar curves of frequency response for all conditions tested (ie, 24-1/2" and 30" pattern-to-lens distance without filter and 24-1/2" pattern-to-lens distance with 1.0 optical density (OD) filter). If the curve formed by the data points were extended, the 10% modulation region would be expected to lie between 2.0 and 2.3 line pairs (lp) per mm, corresponding to approximately 750 to 950 TV lines per picture height. It should be noted that the camera specification called for a center field resolution of 800 TV lines; thus conditions tested met specifications for center field.

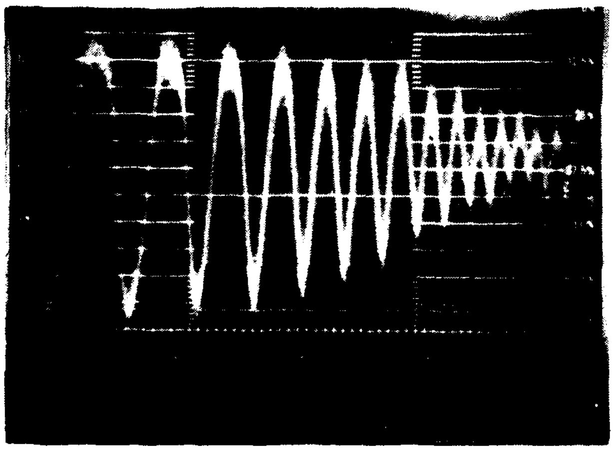
Figure 62 (corner field response) showed a slight decrease in frequency response for the conditions tested. The approximate values of TV lines per picture height for each of the corner conditions test, as evaluated from the 10% modulation region, were as follows:

Test Condition	TV Lines Per Picture Height
24-1/2" pattern-to-lens distance/no filter	685
30" pattern-to-lens distance/no filter	475
24-1/2" pattern-to-lens distance/with filter	455

The camera specifications called for 550 TV lines for corner resolution, which only the 24-1/2" pattern-to-lens distance/no filter met. The disparity between the camera specifications and the results measured herein may be attributed to the lens system, at least in part. With the 1.0 OD filter in place, a wider camera aperture had to

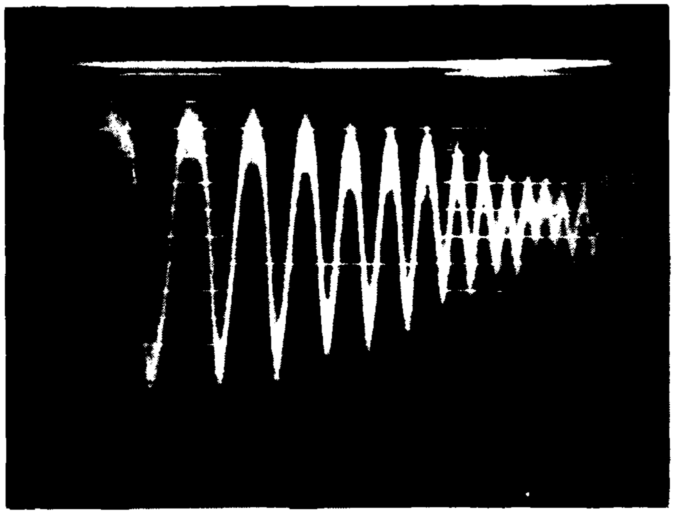


(a) 24-1/2" pattern-to-lens distance
(5 microseconds per division sweep rate)

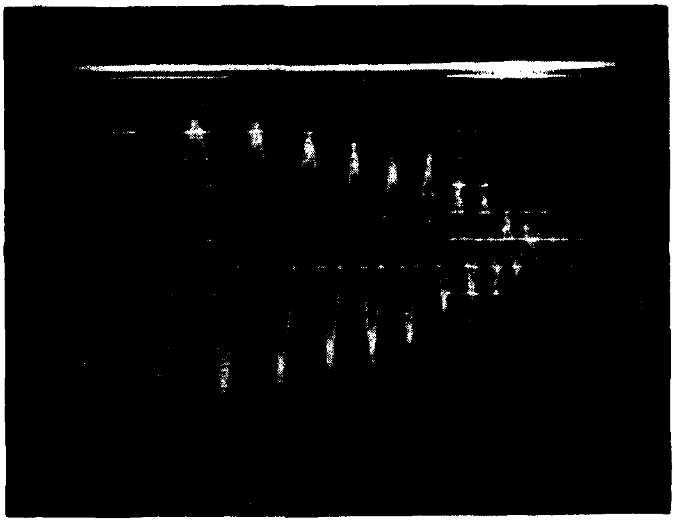


(b) 24-1/2" pattern-to-lens distance
starting at 0.41 lp/mm
(0.25 microseconds per division sweep rate)

Figure 59. Horizontal resolution photographs for TV camera/lens system at center field.



(a) 30" pattern-to-lens distance
starting at 0.41 lp/mm
(0.25 microseconds per division sweep rate)



(b) 24-1/2" pattern-to-lens distance + 1.0 OD filter
starting at 0.41 lp/mm
(0.25 microseconds per division sweep rate)

Figure 60. Horizontal resolution photographs for TV camera/lens system at center field.

Resolution (lp/mm)	Normalized Amplitude: 24-1/2" Pattern-to-Lens	24-1/2" Pattern-to-Lens + Filter	30" Pattern-to-Lens
0.05	1.00	1.00	1.00
0.10	1.00	1.00	1.00
0.20	1.00	1.00	1.00
0.30	1.00	1.00	1.00
0.41	0.95	1.00	0.98
0.50	0.90	0.99	0.91
0.60	0.83	0.92	0.88
0.70	0.80	0.85	0.82
0.82	0.71	0.74	0.67
0.91	0.64	0.68	0.64
1.03	0.58	0.64	0.60
1.24	0.42	0.43	0.42
1.38	0.38	0.39	0.35
1.70	0.25	0.27	0.23
1.80	0.22	0.21	0.22
1.90	0.18	0.18	0.18

Table 8. Horizontal resolution test data for center of field for TV camera/lens system (CGM camera).

Resolution (lp/mm)	Normalized Amplitude: 24-1/2" Pattern-to-Lens	24-1/2" Pattern-to-Lens + Filter	30" Pattern-to-Lens
0.05	1.00	1.00	1.00
0.10	1.00	1.00	1.00
0.20	1.00	1.00	1.00
0.30	1.00	1.00	1.00
0.41	0.93	0.82	0.92
0.50	0.80	0.71	0.97
0.60	0.68	0.56	0.67
0.70	0.58	0.40	0.52
0.82	0.46	0.30	0.40
0.91	0.39	0.21	0.32
1.03	0.31	0.18	0.20
1.24	0.15	0.09	0.11
1.38	0.10		

Table 9. Horizontal resolution test data for corner of field for TV camera/lens system (CGM camera).

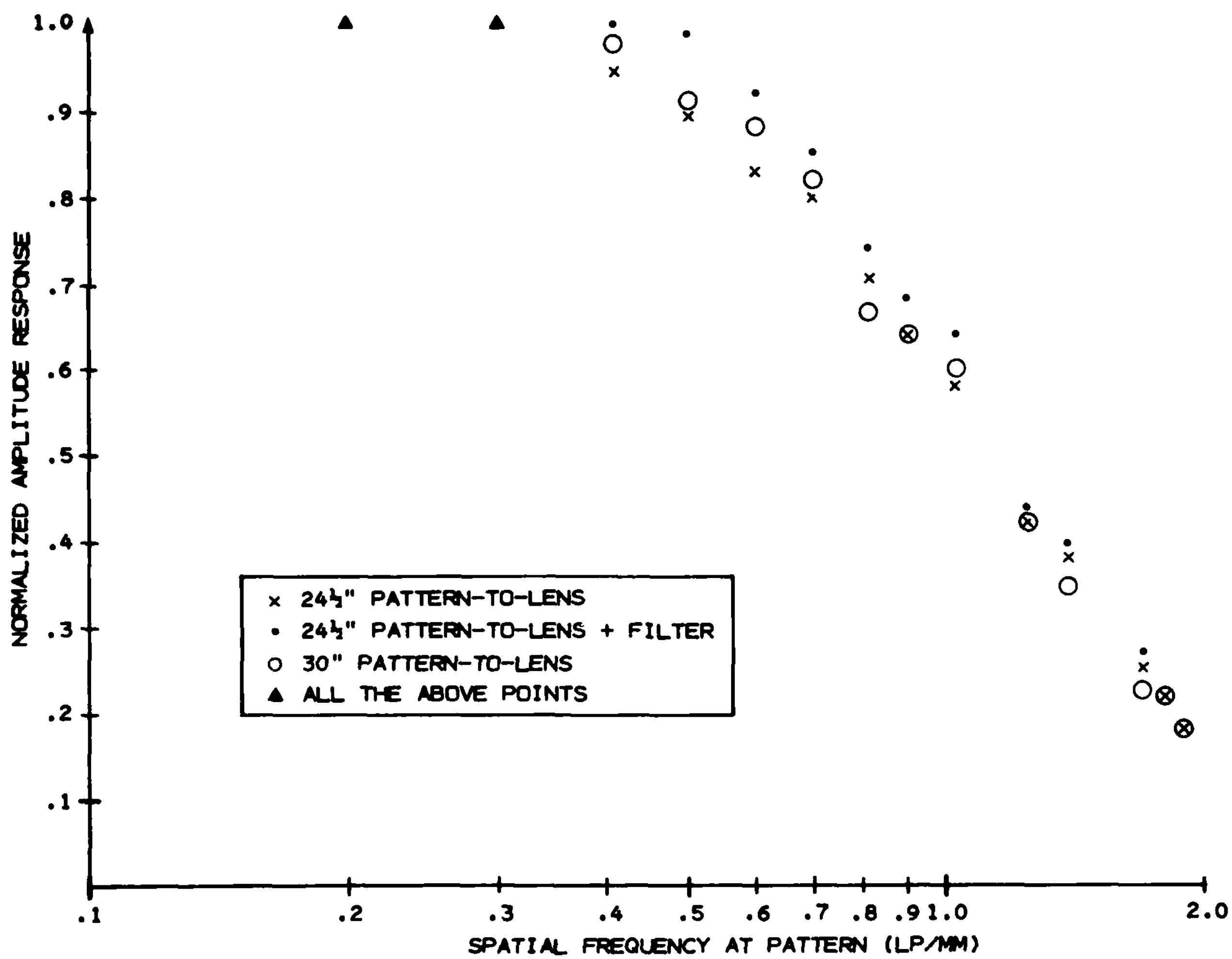


Figure 61. Normalized frequency response for field center, TV camera/lens system.

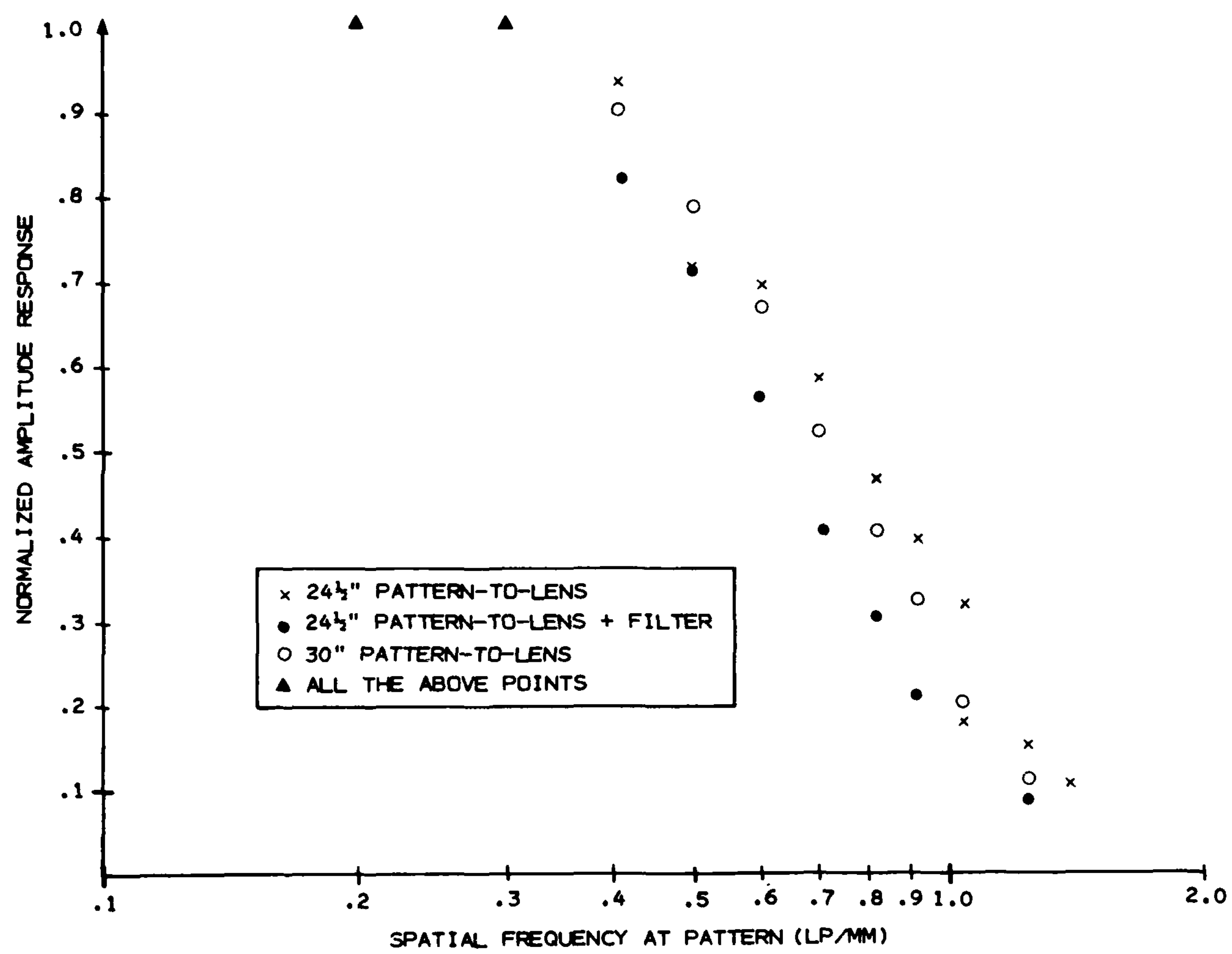


Figure 62. Normalized frequency response for field corner, TV camera/lens system.

be used to achieve an appropriate signal level. This affected the edges of the lens field that correspond to corner field of view and caused distortion in that area. The readjustment of the zoom lens setting, in the case of the 30" pattern-to-lens distance, also caused increased distortion in the corner field of view. The fact that the center field response for the 30" pattern-to-lens distance met specifications under similar test conditions indicated that the increased distortion in the corner field of view was due to a lens edge imaging problem. These effects are consistent with lens theory.

Laboratory Retesting

The Cohu TV camera was tested for center field response with a 24-1/2" pattern-to-lens distance. Figure 63 is a photograph taken from the oscilloscope display. Table 10 gives the recorded measurements of peak-to-peak normalized amplitude versus line pair spatial frequency. The data of table 10 are plotted in figure 64.

Resolution (lp/mm)	Normalized Amplitude
0.05	1.00
0.10	1.00
0.20	1.00
0.30	0.95
0.41	0.91
0.50	0.90
0.60	0.84
0.70	0.78
0.82	0.69
0.91	0.66
1.03	0.55
1.24	0.36
1.38	0.30
1.70	0.18
1.80	0.15
1.90	0.12

Table 10. Horizontal resolution test data for TV camera/lens system (Cohu camera).

As seen in figure 64, the 10% modulation region was expected at approximately 2 line pairs per mm, which corresponds to 760 TV lines per picture height. This value of horizontal resolution was equal to that obtained for the CGM camera for 24-1/2" pattern-to-lens distance, center field response.

5.3.2 Frame Freeze (Video Disc Recorder)

Original Testing

Horizontal resolution measurements were taken for center and lower left corner fields by using the video recorder for image storage. Figure 65 shows photographs taken of the oscilloscope for both center and corner fields. The peak-to-peak

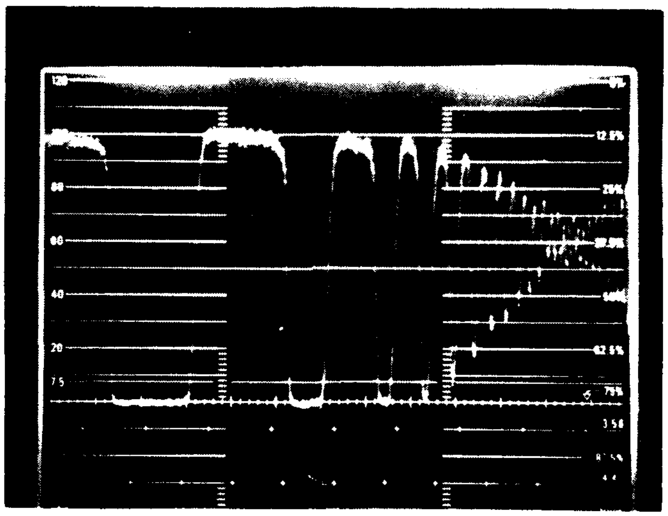


Figure 63. Horizontal resolution photographs for Cohu camera.

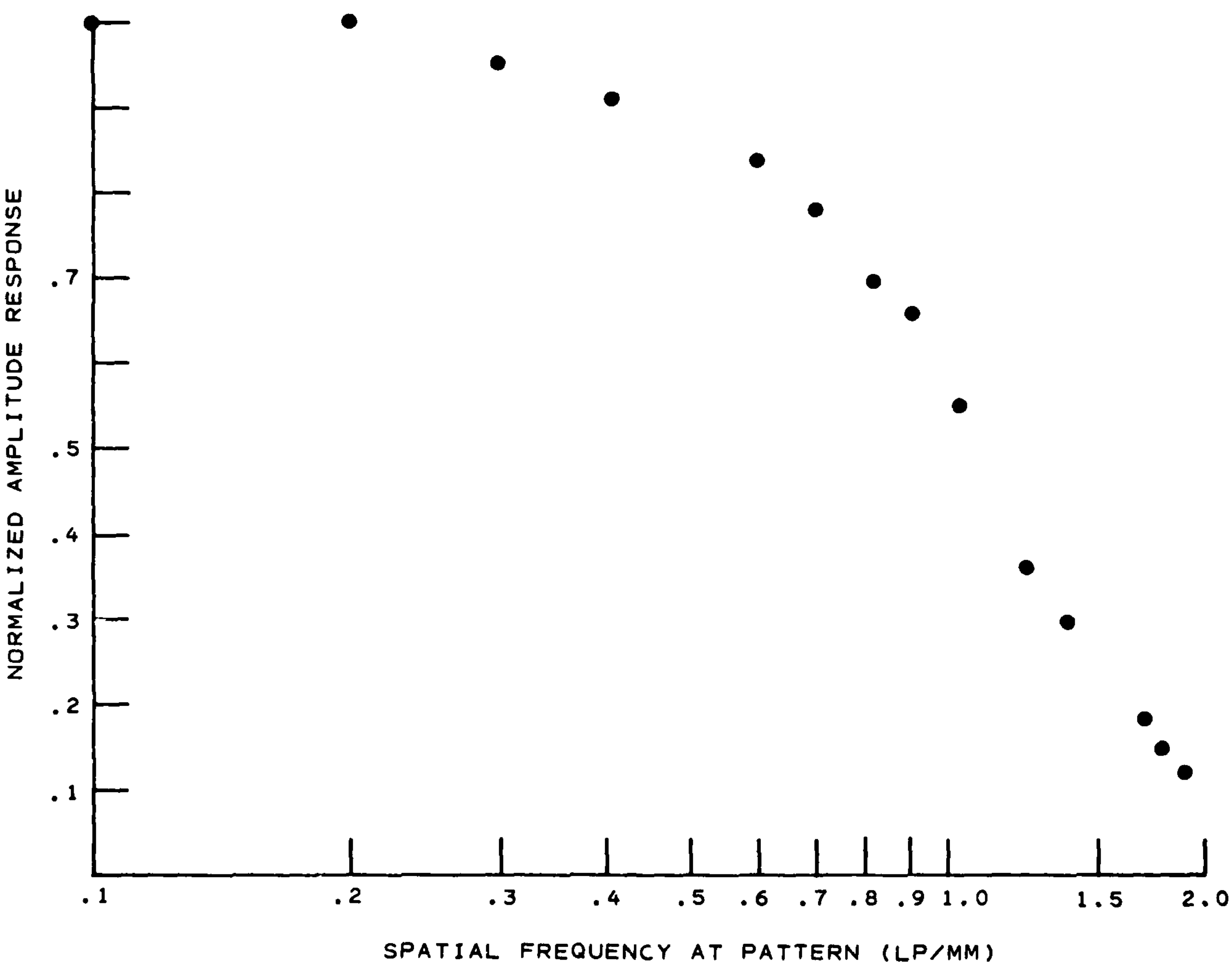
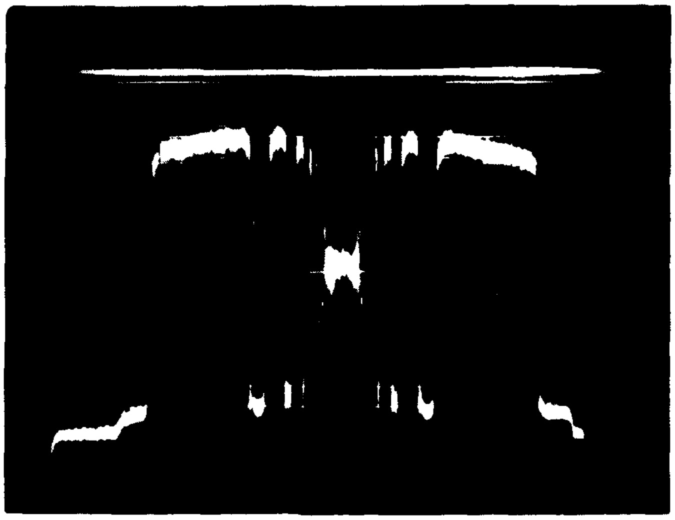
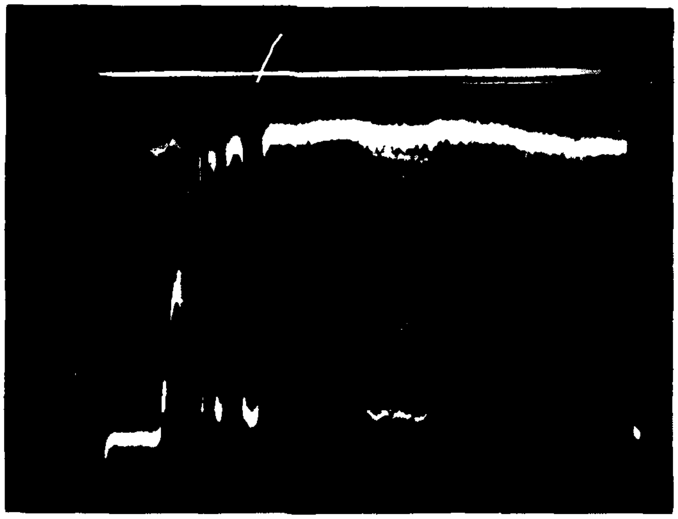


Figure 64. Normalized frequency response for Cohu camera.



(a) Center



(b) Lower left corner

Figure 65. Horizontal resolution photographs for frame freeze.

normalized amplitude measurements versus line pair spatial frequency for both center and corner field response are listed in table 11 and plotted in figure 66.

Resolution (lp/mm)	Normalized Amplitude Center of Field	Normalized Amplitude Corner of Field
0.05	1.00	1.00
0.10	1.00	1.00
0.20	1.00	1.00
0.30	1.00	1.00
0.41	0.80	0.71
0.50	0.67	0.56
0.60	0.43	0.34
0.70	0.28	0.13
0.82	0.18	0.05
0.91	0.09	

Table 11. Horizontal resolution test data for frame freeze (CGM camera).

Figure 66 shows that the corner field response was less than the center field response — an expected result. At the 10% modulation level, the corner field had approximately 0.76 line pair per mm, while the center field had approximately 0.9 line pair per mm. These values correspond to a bandwidth of roughly 3.5 and 4.2 MHz, respectively. The best response for the disc recorder was approximately 4.5 MHz; test results indicated good center field response. Decreased response for corner field can be attributed to lens distortion. (See section 5.3.1.)

Laboratory Retesting

Horizontal resolution measurements were taken for center field response by using the video disc recorder for image storage via the Cohu camera. Figure 67 shows a photograph taken of the oscilloscope display. The peak-to-peak normalized amplitude measurements versus line pair spatial frequency are listed in table 12 and plotted in figure 68.

Resolution (lp/mm)	Normalized Amplitude
0.05	1.00
0.10	1.00
0.20	1.00
0.30	0.98
0.41	0.92
0.50	0.84
0.60	0.54
0.70	0.28
0.82	0.10

Table 12. Horizontal resolution test data for frame freeze (Cohu camera).

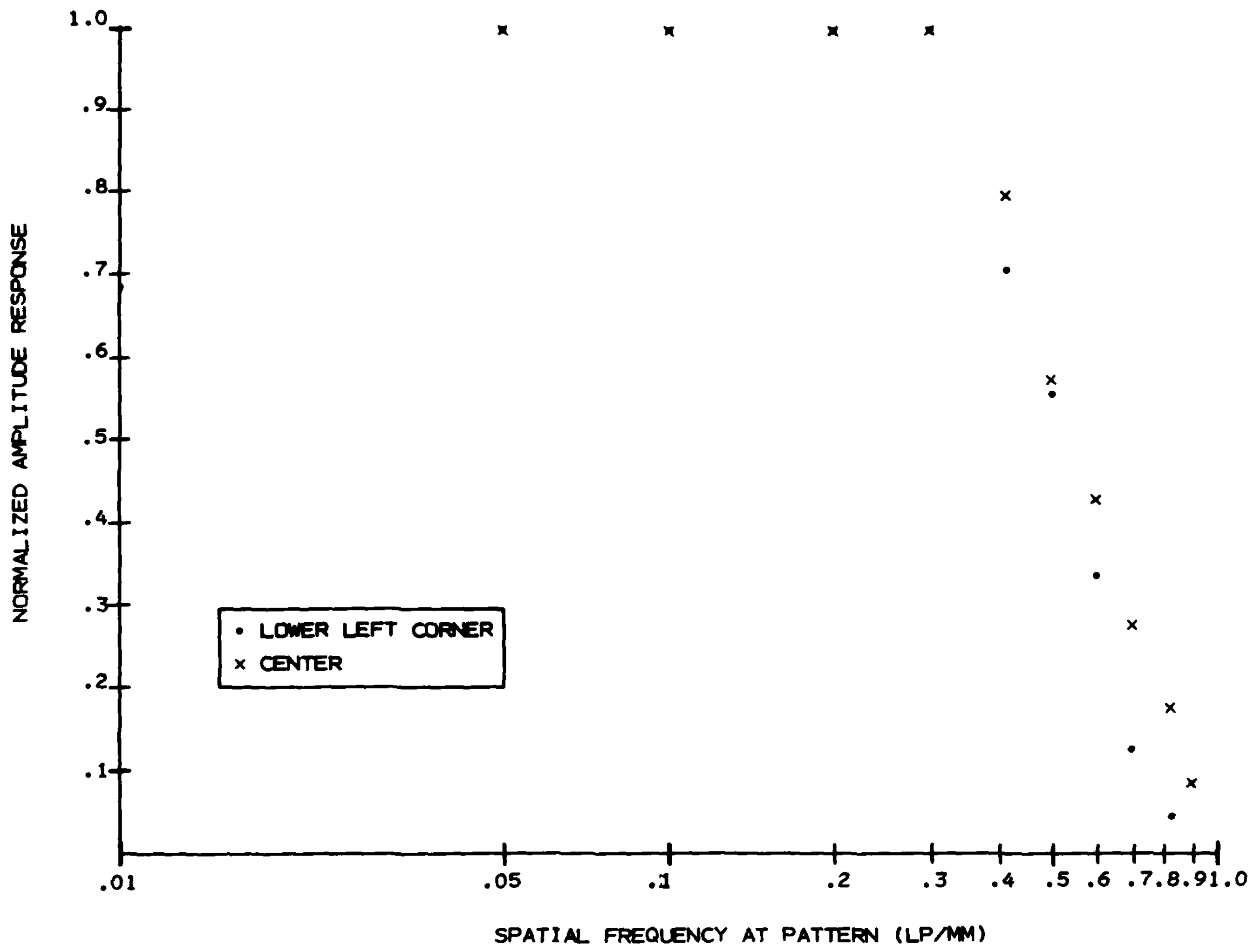


Figure 66. Normalized frequency response for frame freeze (video recorder).

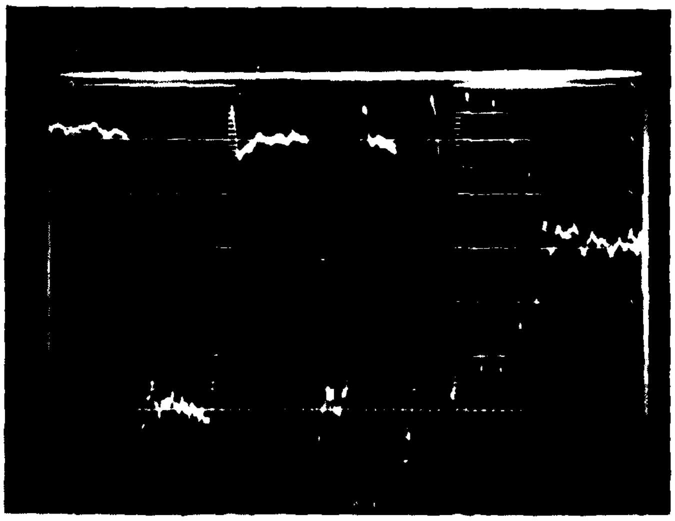


Figure 67. Horizontal resolution photograph for frame freeze, Cohu camera.

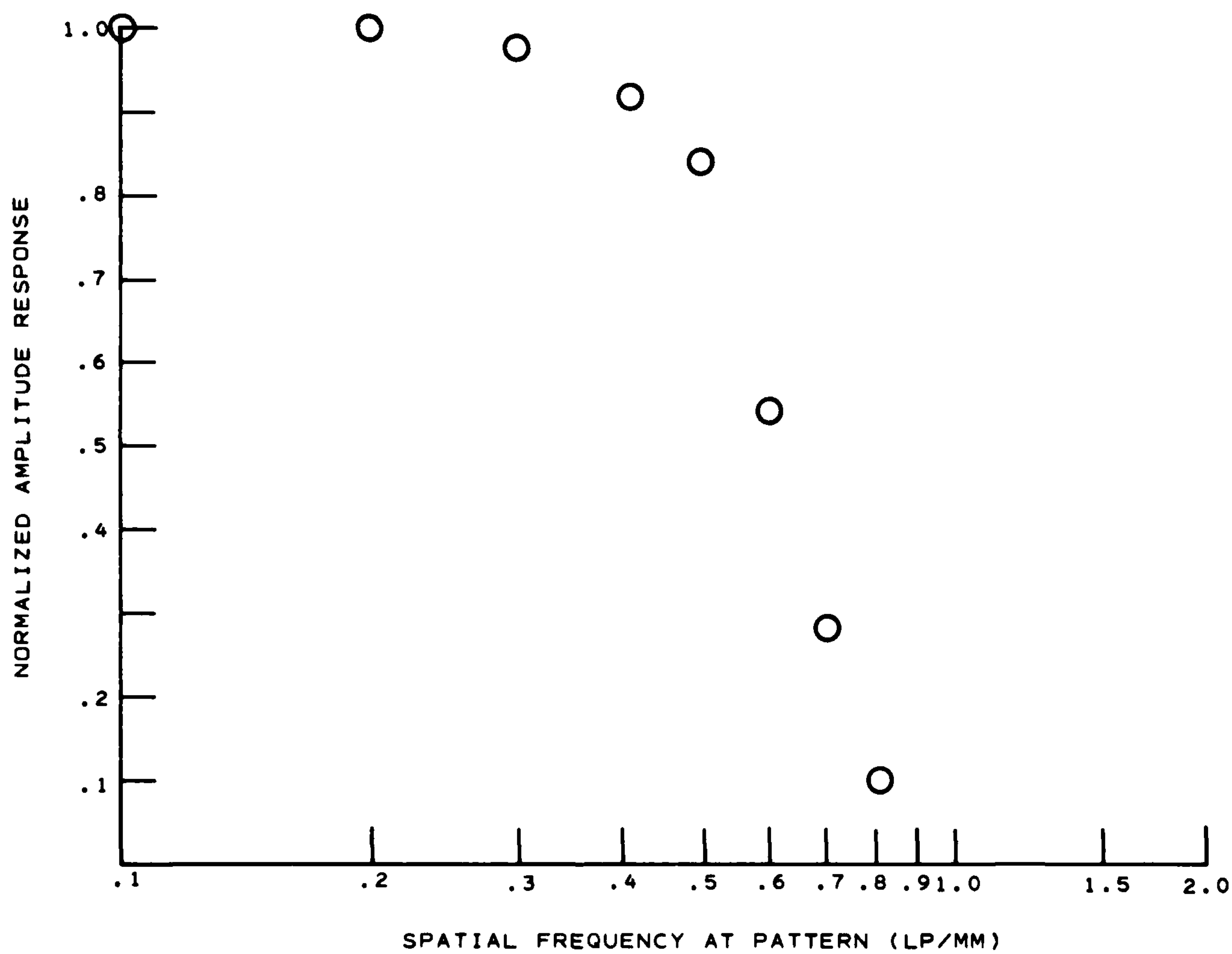


Figure 68. Normalized frequency response for frame freeze, Cohu image.

As seen in figure 68, the 10% modulation region was expected at approximately 0.82 line pair per mm, which corresponds to 310 TV lines per picture height and a bandwidth of 3.8 MHz. The best response for the disc recorder is approximately 4.5 MHz; test results indicated good center field response. It should be noted that the results of the Cohu camera test closely correspond to CGM camera testing.

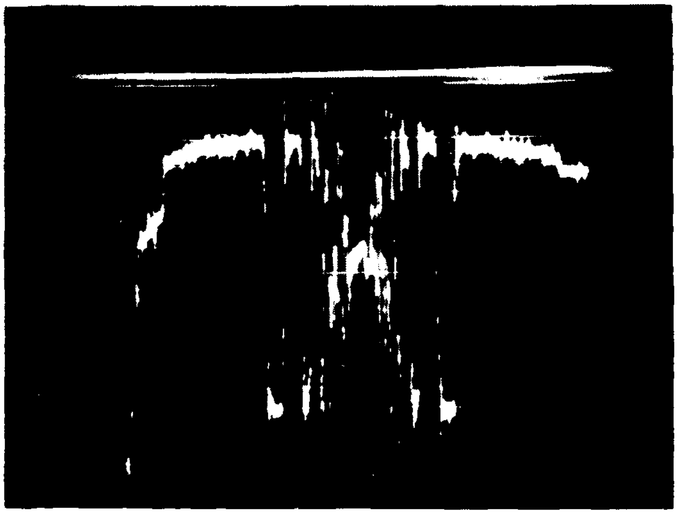
5.3.3 Analog Video Transmission

Original Testing

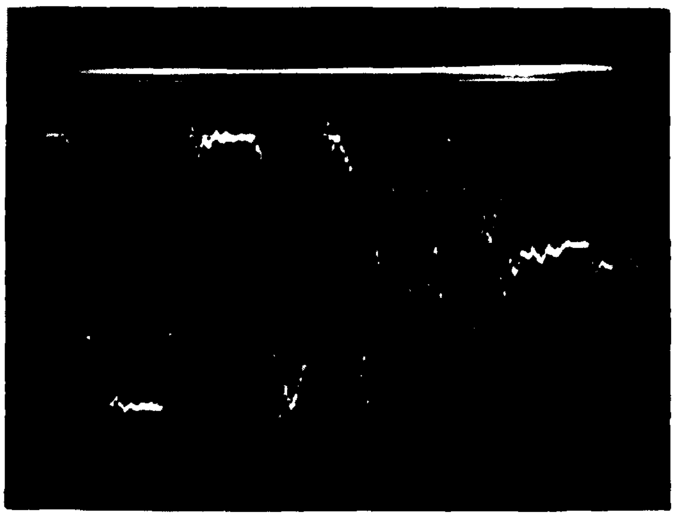
Testing was conducted for received resolution response of center and corner field of view images as transmitted via the CGM camera, RMDS analog video mode. The transmitting and receiving terminals were linked in back-to-back, local telephone line, and long distance telephone line communication configurations. The image signals were transmitted via the fine resolution mode. Additional tests were performed by using an image signal recorded on the transmitter terminal's video disc recorder, and then transmitted over the communication links listed above. The video signal at the output of the receiving terminal's monitor was input to an oscilloscope for display of a horizontal line of the video signal through the bar pattern in the center of the field. Figures 69 and 70 show representative photographs of the horizontal line of video signal for the bar pattern. As seen in the photographs, a substantial amount of noise was present in the signal. Amplitude measurements were complicated by the excessive amount of ringing accompanying the pulses. The ringing had a frequency of approximately 4 MHz and a decay time of 1 microsecond. It had the greatest effect beyond the 0.41 line pair per mm region, which corresponds to approximately a 2 MHz pattern signal. It should be noted that the video bandwidth compressor sampling circuit had a 4 MHz cutoff filter, which would limit the resolution at 0.87 line pair per mm for analog and digital video transmission. The ringing seen in both analog and digital modes (section 5.3.4) could have been caused by underdamping of this filter. A check of this circuit should be performed. The spatial frequency response for the situations under consideration, while difficult to determine, obviously deteriorated much faster than in any of the previously discussed test situations. The reduced data from photographs (figures 69 and 70) and the other conditions tested are shown in tables 13, 14, and 15 and are plotted in part as figures 71, 72, and 73. Determining a limiting resolution from these data was difficult because of the lack of monoticity and uniformity in the response versus increasing frequency and because the amplitude response to the spatial frequencies applied fell off extremely rapidly into the noise, as shown in figures 69 and 70. Nonetheless, the 25 and 50% modulation resolutions were estimated from the data shown in figures 71, 72, and 73 and are listed in table 16.

The horizontal resolution in the analog transmission mode decreased when 1) moving from center to lower left corner field of view (as seen in previous tests), 2) as the communication linkage increased in complexity, ie, back-to-back to local telephone line to long distance telephone line, and 3) when the video disc recorder was used in place of a camera's image for transmission. As expected, the video disc recorder's resolution was markedly decreased from the camera's transmitted image, but the type of communication link did not decrease the resolution further in any definite pattern.

The resolution at the 10% modulation region was not estimated, since consistent data points in that area were lacking. Because of the rapid roll-off in

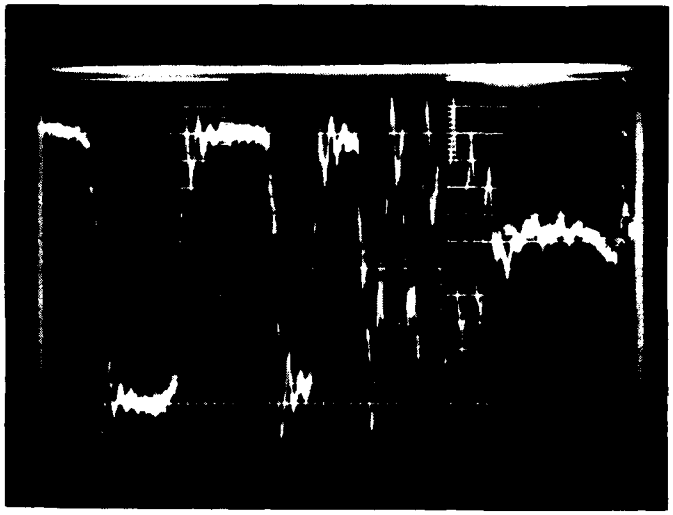


(a) Center field
(5 microseconds per division sweep rate)



(b) Center field
(1 microsecond per division sweep rate)

Figure 69. Horizontal resolution photographs for analog video transmission, back-to-back.



(a) Local telephone line, center field
(1 microsecond per division sweep rate)

(b) Long distance telephone line, center field
(1 microsecond per division sweep rate)

Figure 70. Horizontal resolution photographs for analog video transmission, local and long distance telephone lines.

Resolution (lp/mm)	Normalized Amplitude: Center of Field, Camera Image	Center of Field, Frame Freeze	Corner of Field, Camera Image	Corner of Field, Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00
0.20	0.96	0.94	0.94	0.83
0.30	0.84	0.86	0.83	0.70
0.41	0.48	0.84	0.68	0.63
0.50	0.73	0.53	0.68	0.40
0.60	0.48	0.26	0.51	0.25
0.70	*	0.20		
0.82	0.15			

*Measurement masked by excessive ringing

Table 13. Horizontal resolution test data for back-to-back communication link of analog video transmission mode (CGM camera).

Resolution (lp/mm)	Normalized Amplitude: Center of Field, Camera Image	Center of Field, Frame Freeze	Corner of Field, Camera Image	Corner of Field, Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00
0.20	0.85	0.90	0.95	1.00
0.30	0.80	0.86	0.80	0.86
0.41	0.80	0.90	0.77	0.73
0.50	0.69	0.28	0.63	0.17
0.60	0.54	0.34	0.42	0.10
0.70		0.18		

Table 14. Horizontal resolution test data for local telephone line communication link of analog video transmission mode (CGM camera).

Resolution (lp/mm)	Normalized Amplitude Center of Field	
	Camera Image	Frame Freeze
0.05	1.00	1.00
0.10	1.00	1.00
0.20	0.98	1.00
0.30	0.82	0.78
0.41	0.94	0.78
0.50	0.20	0.88
0.60	0.20	0.42
0.70	0.18	0.18
0.82	0.08	0.12

Table 15. Horizontal resolution test data for long distance telephone line communication link of analog video transmission mode (CGM camera).

Condition Tested	Line Pairs per mm		TV Lines Across in Horizontal Direction	
	50% Mod	25% Mod	50% Mod	25% Mod
Back-to-Back link (fig. 71)				
Lower Left Corner	0.61	0.73	310	370
Lower Left Corner/Disc*	0.42	0.59	215	300
Center	0.57	0.70	290	355
Center/Disc*	0.53	0.61	270	310
Center Field (fig. 72)				
Back-to-Back	0.57	0.70	290	355
Local Telephone Line	0.63	0.68	320	345
Long Distance Telephone Line	0.43	0.48	220	245
Center Field/Disc (fig. 73)				
Back-to-Back	0.53	0.61	270	310
Local Telephone Line	0.48	0.63	245	320
Long Distance Telephone Line	0.55	0.65	280	330

*Disc = Frame Freeze

Table 16. Horizontal resolution for analog transmission mode for the 25 and 50% modulation regions (CGM camera).

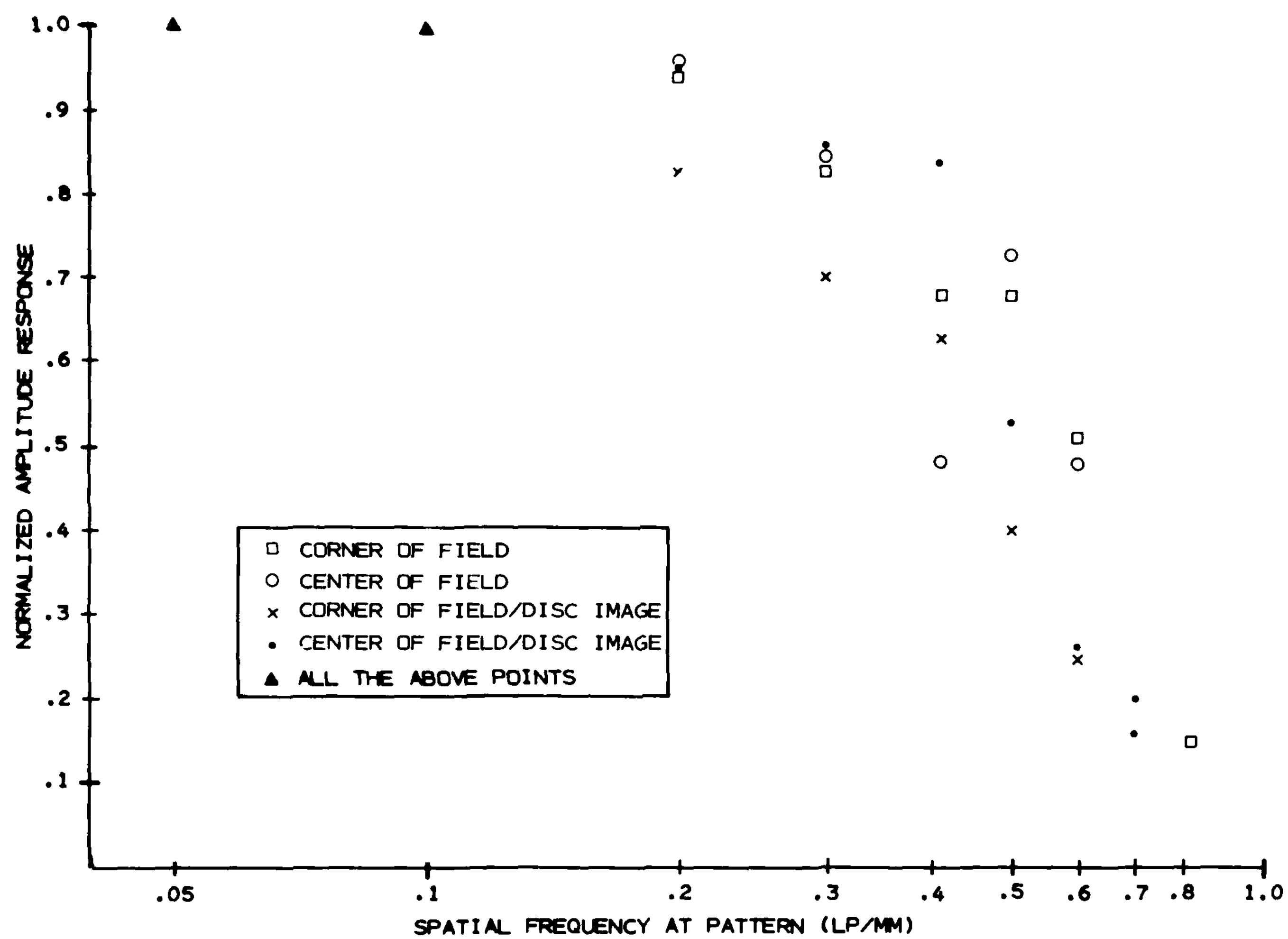


Figure 71. Normalized frequency response for analog video transmission mode, back-to-back communication link.

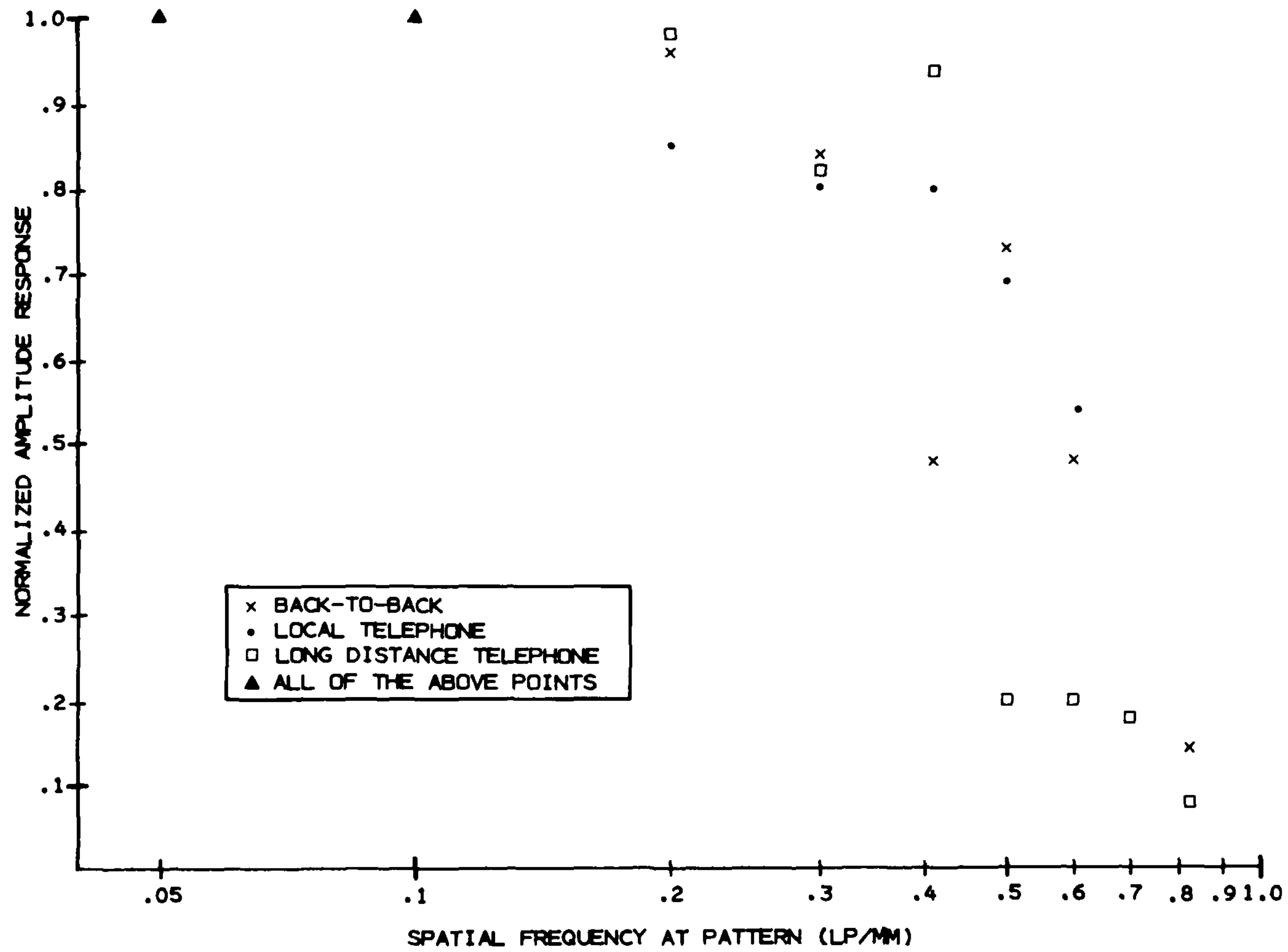


Figure 72. Normalized frequency response for center field, analog video transmission mode.

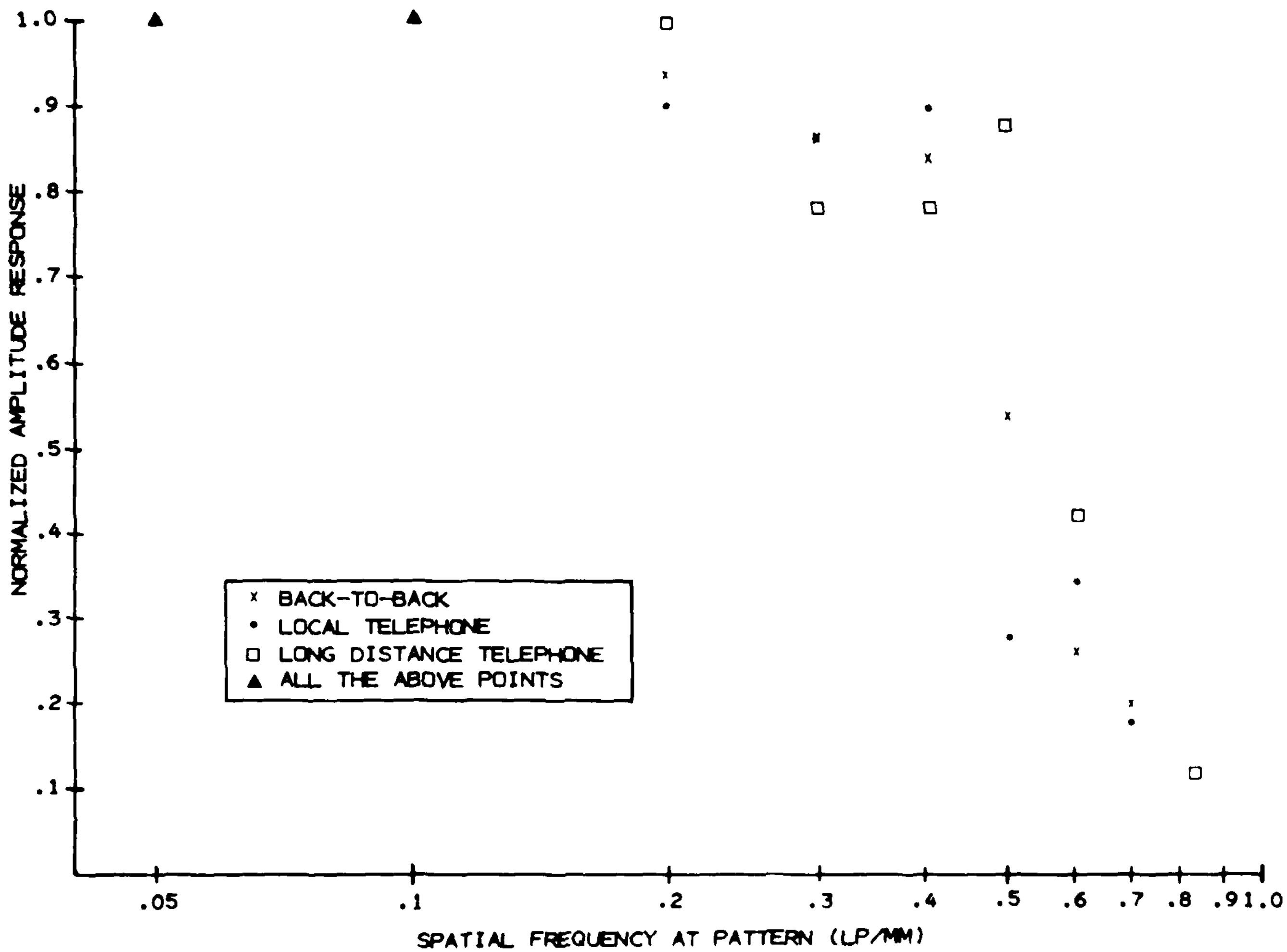


Figure 73. Normalized frequency response for center field, analog video transmission mode, disc recorder.

response, the data indicated a resolution value approximately the same as that for the 25% modulation level. From the limited set of data, it appeared that the RMDS terminals are capable of transmitting video images in the analog mode with 0.5 line pair per mm of resolution at the 50% amplitude response for a 7-1/2 x 10 inch field size under the conditions tested.

Laboratory Retesting

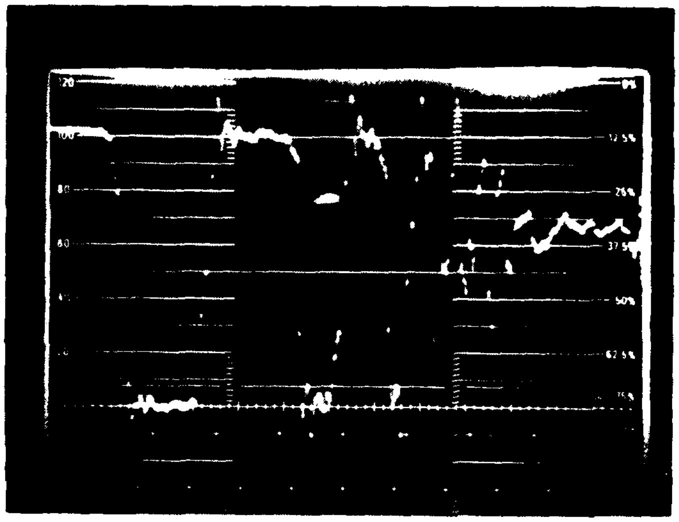
Testing was conducted for received resolution response of images as transmitted via the analog video mode. The Cohu camera and frame freeze were used as image sources. The transmitting and receiving terminals were linked in a back-to-back communication configuration, and image signals were transmitted via the fine resolution mode. The video signal at the output of the receiving unit's monitor was input to an oscilloscope for resolution measurement; figure 74 shows representative photographs of the oscilloscope display.

Amplitude measurements were complicated by an excessive amount of ringing accompanying the pulses. Similar ringing was noted in the original testing period as previously described. The spatial frequency response, while difficult to determine, was reduced from photographs similar to figure 74. The peak-to-peak normalized amplitude versus line pair spatial frequency for the conditions tested are listed in table 17 and plotted in figure 75.

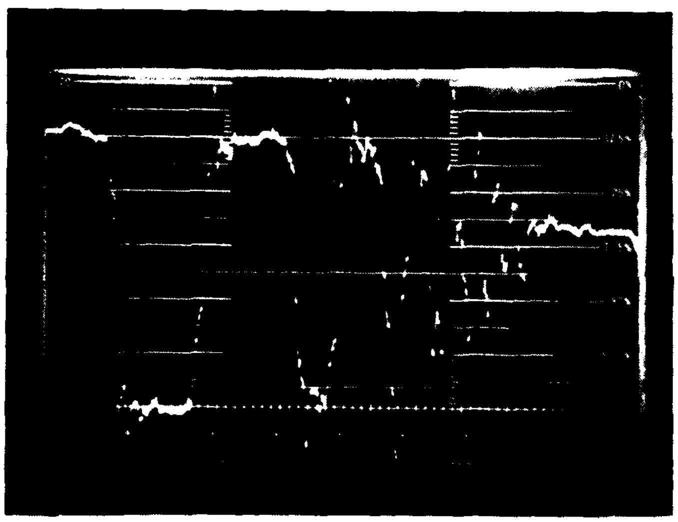
	Normalized Amplitude	
Resolution (lp/mm)	Camera Image	Frame Freeze
0.05	1.00	1.00
0.10	1.00	0.97
0.20	0.95	0.90
0.30	0.90	0.75
0.41	0.37	0.60
0.50	0.40	0.42
0.60	0.15	0.23
0.70		0.15

Table 17. Horizontal resolution test data for back-to-back communication link of analog video transmission mode (Cohu camera).

Determining a limiting resolution from these data is difficult because of the lack of monoticity and uniformity in the response versus increasing frequency and because the amplitude response to the applied spatial frequencies fell off extremely rapidly into the noise, as shown in figure 75. Nonetheless, the 25 and 50% modulation resolutions were estimated from the data and are listed below.



(a) Camera



(b) Frame freeze

Figure 74. Horizontal resolution photographs for analog fine transmission, back-to-back, Cohu camera.

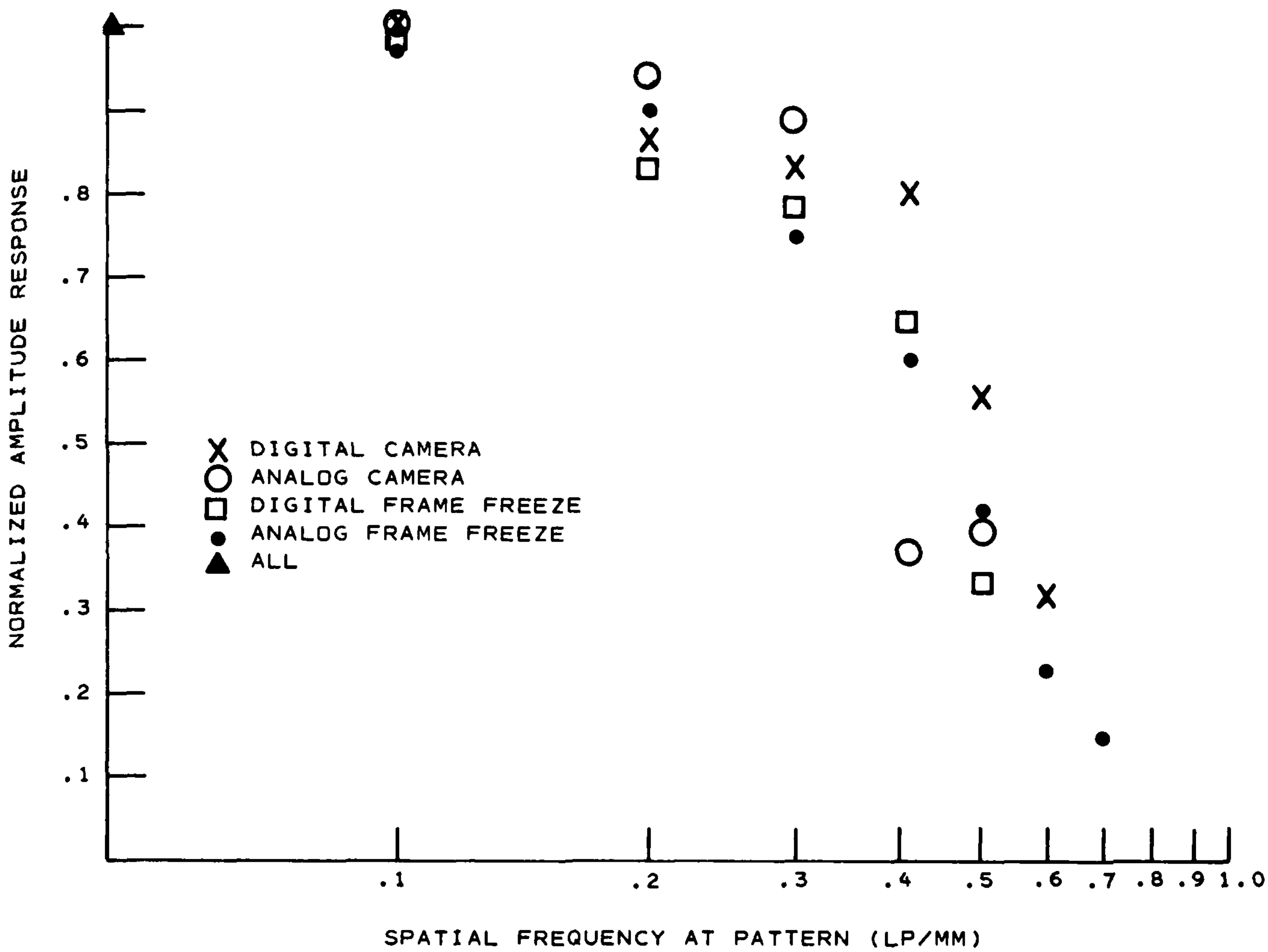


Figure 75. Normalized frequency response for analog and digital video transmission mode, Cohu image.

	Resolution (lp/mm)		TV Lines Across	
Image Source	50% Mod	25% Mod	50% Mod	25% Mod
TV Camera	0.46	0.56	235	285
Frame Freeze	0.46	0.58	235	295

Horizontal resolution measurements obtained via the Cohu camera were comparable to those obtained for the CGM camera.

5.3.4 Digital Video Transmission

Original Testing

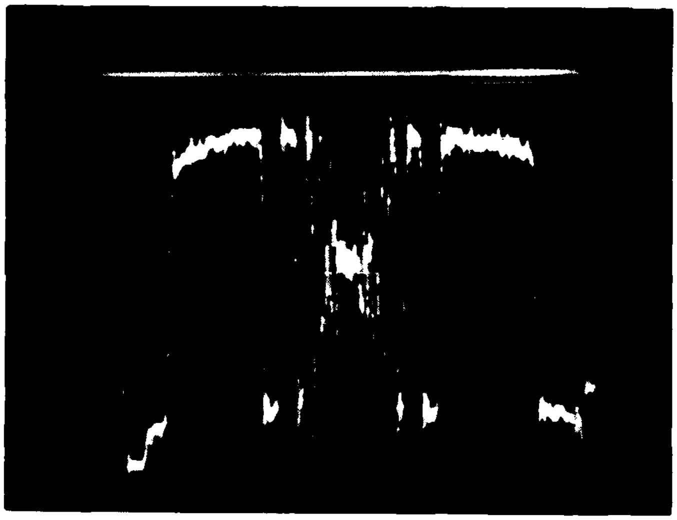
Testing was conducted for received resolution response of images in the center and corner field of view as transmitted via the CGM camera, RMDS digital video mode. The transmitting and receiving terminals were linked in back-to-back, local telephone line, and long distance telephone line configurations. In the local telephone and long distance telephone line links, coarse and fine resolution modes were employed. The back-to-back communication link was operated only in a fine resolution mode. Due to the types of modems and the telephone lines used, digital video transmission could be performed only at the 2400 bps rate. In the back-to-back communication link a comparison was made between the 9600 and 2400 bps modes. Additional tests were performed by using an image recorded on the transmitter terminal's frame freeze (video disc recorder), then transmitted under the conditions listed above. The procedures for obtaining and analyzing data were identical to those used for the analog video transmission.

Figures 76 and 77 show representative photographs of a horizontal line of video signal for the bar pattern in the center field as received at the receiving terminal. The same type of noise and ringing seen in the analog video transmission mode (figures 69 and 70) were present in the digital mode, and determining frequency response was similarly complicated by the ringing and rapid roll-off of the signal at higher spatial frequencies. The reduced data from these photographs (figures 76 and 77) and the other conditions tested are shown in tables 18 through 23 and plotted in part as figures 78 through 82.

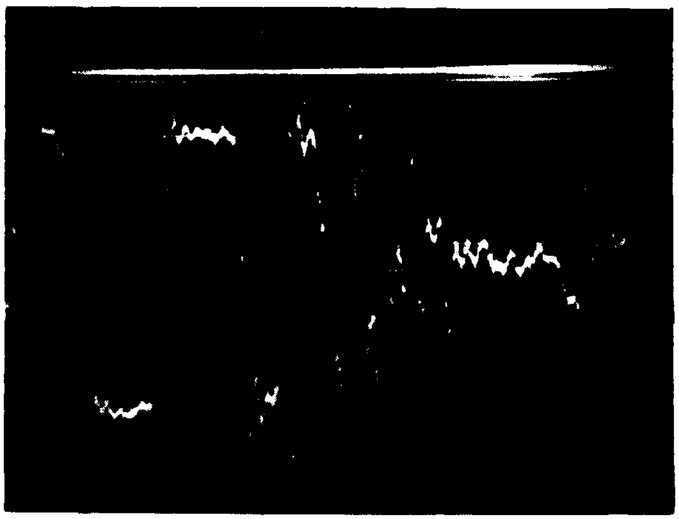
The effects of the ringing and the nominal data obtained from these tests made an estimation of any reasonable accuracy of the limiting resolution point inappropriate. As can be seen in figures 78 through 82, the curves of frequency response for all conditions tested are similar in shape, and, aside from ringing effects, they transverse the area of 50% modulation level in the range of 0.4 to 0.6 line pairs per mm. This corresponds to approximately 205 and 305 TV lines across horizontally. As noted in the analog video transmission (section 5.3.3), an underdamped 4 MHz cutoff filter would reduce the resolution to the level seen under these test conditions.

Laboratory Retesting

Testing was conducted for received resolution response of images transmitted via the digital video mode. The Cohu camera and frame freeze were used as

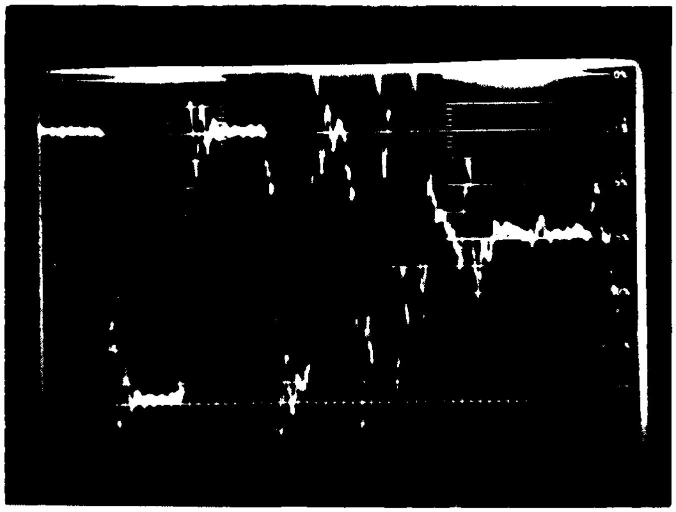


(a) Center field, fine
(5 microseconds per division sweep rate)

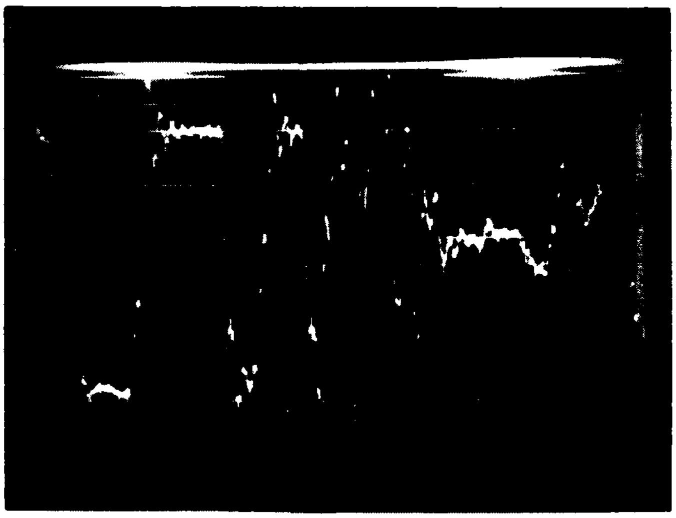


(b) Center field, fine
(1 microsecond per division sweep rate)

Figure 76. Horizontal resolution photographs for digital fine video transmission, back-to-back.



(a) Local telephone line, center field, fine
(1 microsecond per division sweep rate)



(b) Long distance telephone line, center field, fine
(1 microsecond per division sweep rate)

Figure 77. Horizontal resolution photographs for digital video transmission, local and long distance telephone lines.

	Normalized Amplitude			
	Center of Field		Corner of Field	
Resolution (lp/mm)	Camera Image	Frame Freeze	Camera Image	Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00
0.20	0.91	0.90	0.95	0.84
0.30	0.82	0.78	0.86	0.72
0.41	0.70	0.51	0.68	0.38
0.50	0.72	0.12	0.62	
0.60	0.13		0.38	
0.70	0.12			

Table 18. Horizontal resolution test data for back-to-back communication link, 9600 bps digital video transmission (CGM camera).

	Normalized Amplitude			
	Center of Field		Corner of Field	
Resolution (lp/mm)	Camera Image	Frame Freeze	Camera Image	Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00
0.20	0.85	0.83	0.90	0.81
0.30	0.74	0.71	0.85	0.70
0.41	0.48	0.58	0.46	0.42
0.50	0.32	0.20	0.40	0.13
0.60			0.12	0.07

Table 19. Horizontal resolution test data for back-to-back communication link, 2400 bps digital video transmission (CGM camera).

Resolution (lp/mm)	Normalized Amplitude: Center of Field, Camera Image	Center of Field, Frame Freeze	Corner of Field, Camera Image	Corner of Field, Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	1.00	1.00	1.00	1.00
0.20	0.90	0.95	1.00	0.94
0.30	0.70	0.86	0.87	0.90
0.41	0.46	0.90	0.56	0.57
0.50	*	0.28	*	0.50
0.60	0.32	0.40	0.35	

*Measurement masked by excessive ringing

Table 20. Horizontal resolution test data for local telephone line communication link, fine mode of digital video transmission (CGM camera).

Resolution (lp/mm)	Normalized Amplitude Center of Field: Camera Image	Frame Freeze
0.05	1.00	1.00
0.10	1.00	1.00
0.20	0.93	0.90
0.30	0.88	0.64
0.41	0.71	0.51
0.50	0.88	0.33
0.60	0.53	
0.70	*	
0.82	0.23	

*Measurement masked by excessive ringing

Table 21. Horizontal resolution test data for local telephone line communication link, coarse mode of digital video transmission (CGM camera).

Resolution (lp/mm)	Normalized Amplitude: Center of Field: Camera Image	Normalized Amplitude: Center of Field: Frame Freeze	Normalized Amplitude: Corner of Field: Camera Image	Normalized Amplitude: Corner of Field: Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	0.90	1.00	0.92	1.00
0.20	0.85	0.98	0.88	0.98
0.30	0.78	0.92	0.88	0.98
0.411	0.000	0.440	0.430	0.32
0.60	0.49			

Table 22. Horizontal resolution test data for long distance telephone line communication link, fine mode of digital video transmission (CGM camera).

Resolution (lp/mm)	Normalized Amplitude: Center of Field: Camera Image	Normalized Amplitude: Center of Field: Frame Freeze	Normalized Amplitude: Corner of Field: Camera Image	Normalized Amplitude: Corner of Field: Frame Freeze
0.05	1.00	1.00	1.00	1.00
0.10	1.00	0.98	1.00	0.97
0.20	0.98	0.88	0.95	0.94
0.30	0.97	0.80	0.80	0.88
0.41	0.78	0.70	0.78	0.63
0.50	0.39	0.78	0.18	0.22
0.60		0.38		
0.70		0.35		

Table 23. Horizontal resolution test data for long distance telephone line communication link, coarse mode of digital video transmission (CGM camera).

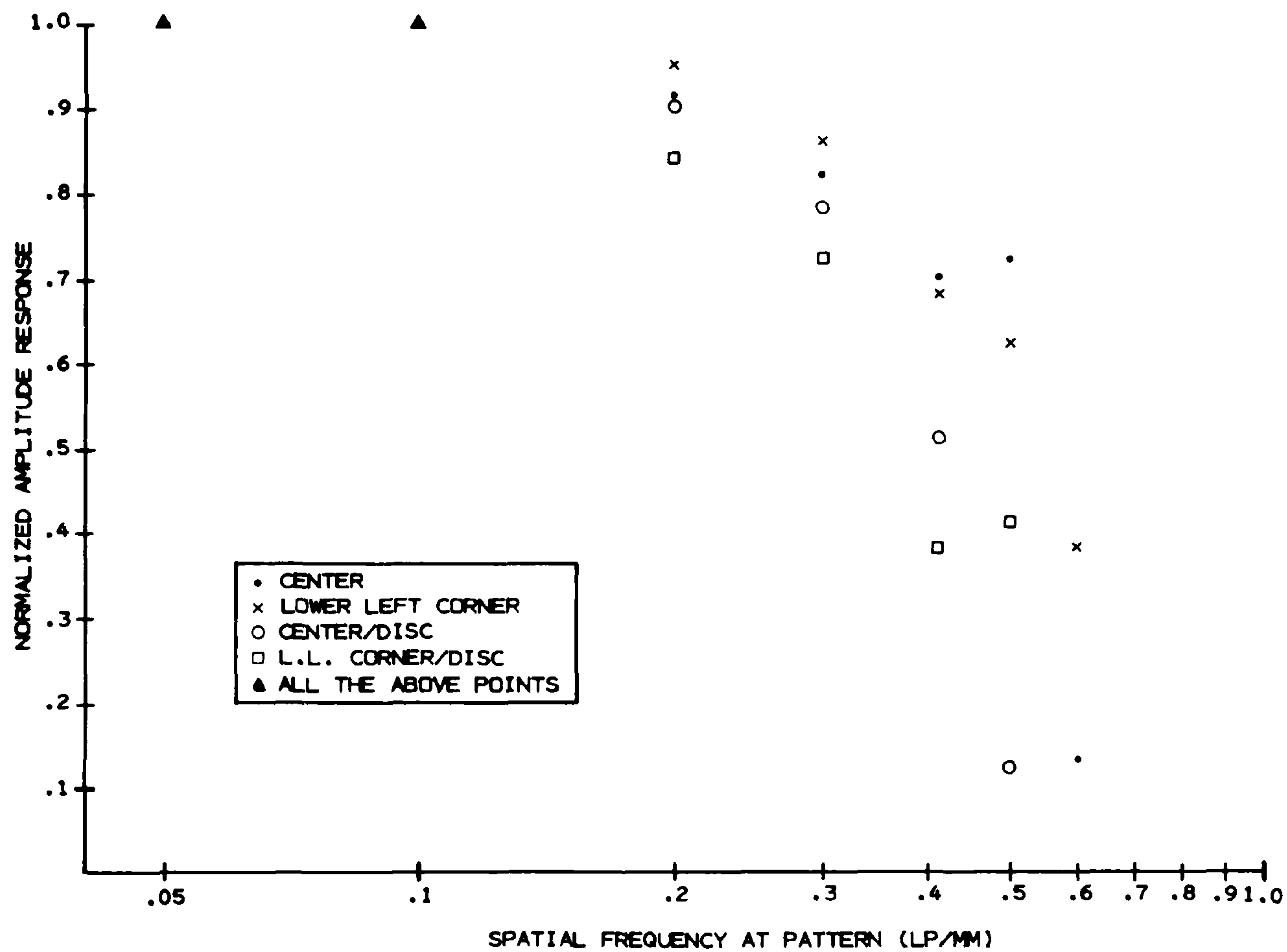


Figure 78. Normalized frequency response for digital video transmission, 9600 bps, back-to-back.

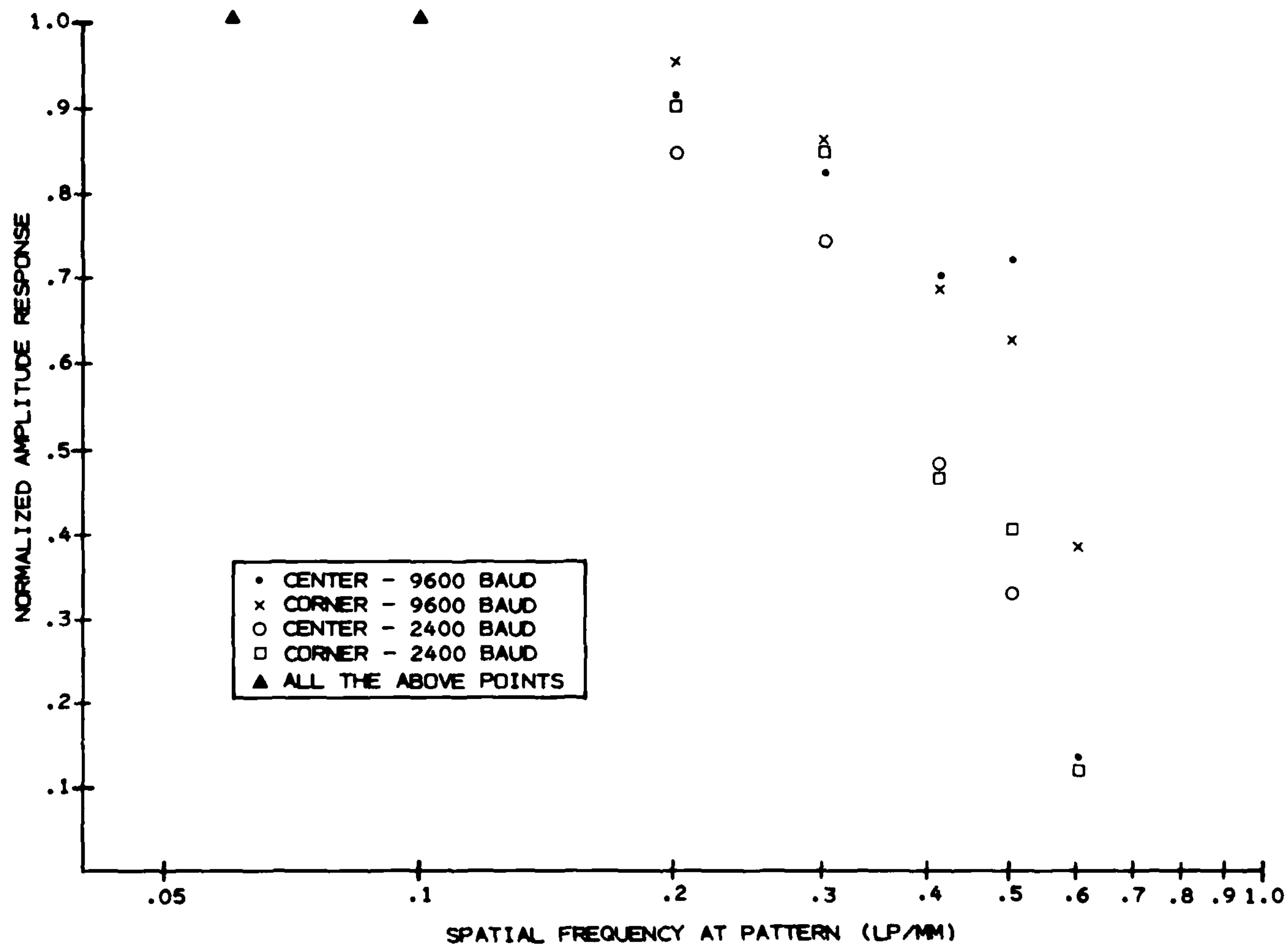


Figure 79. Normalized frequency response for digital video transmission, back-to-back.

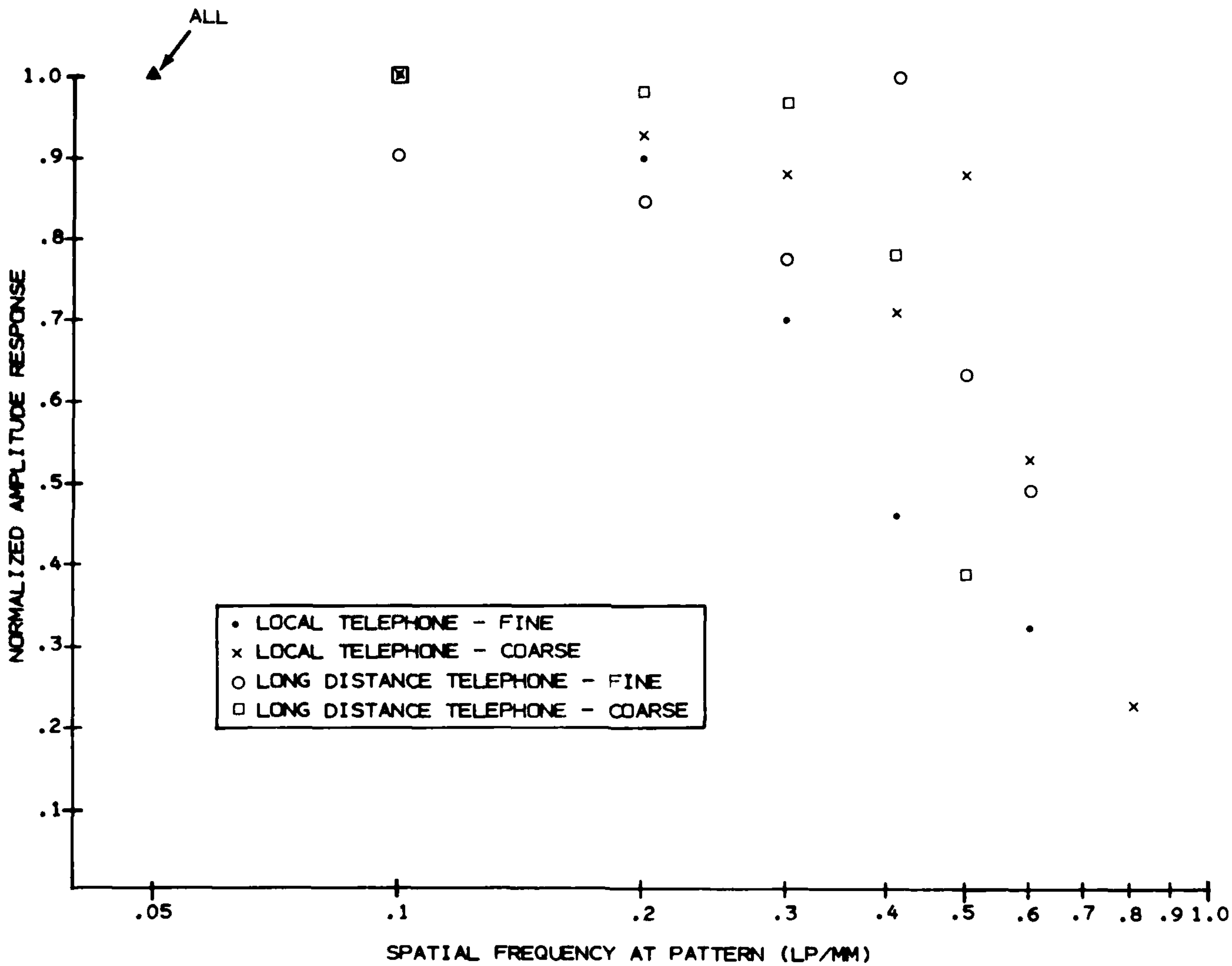


Figure 80. Normalized frequency response for center field, digital video transmission mode, coarse/fine.

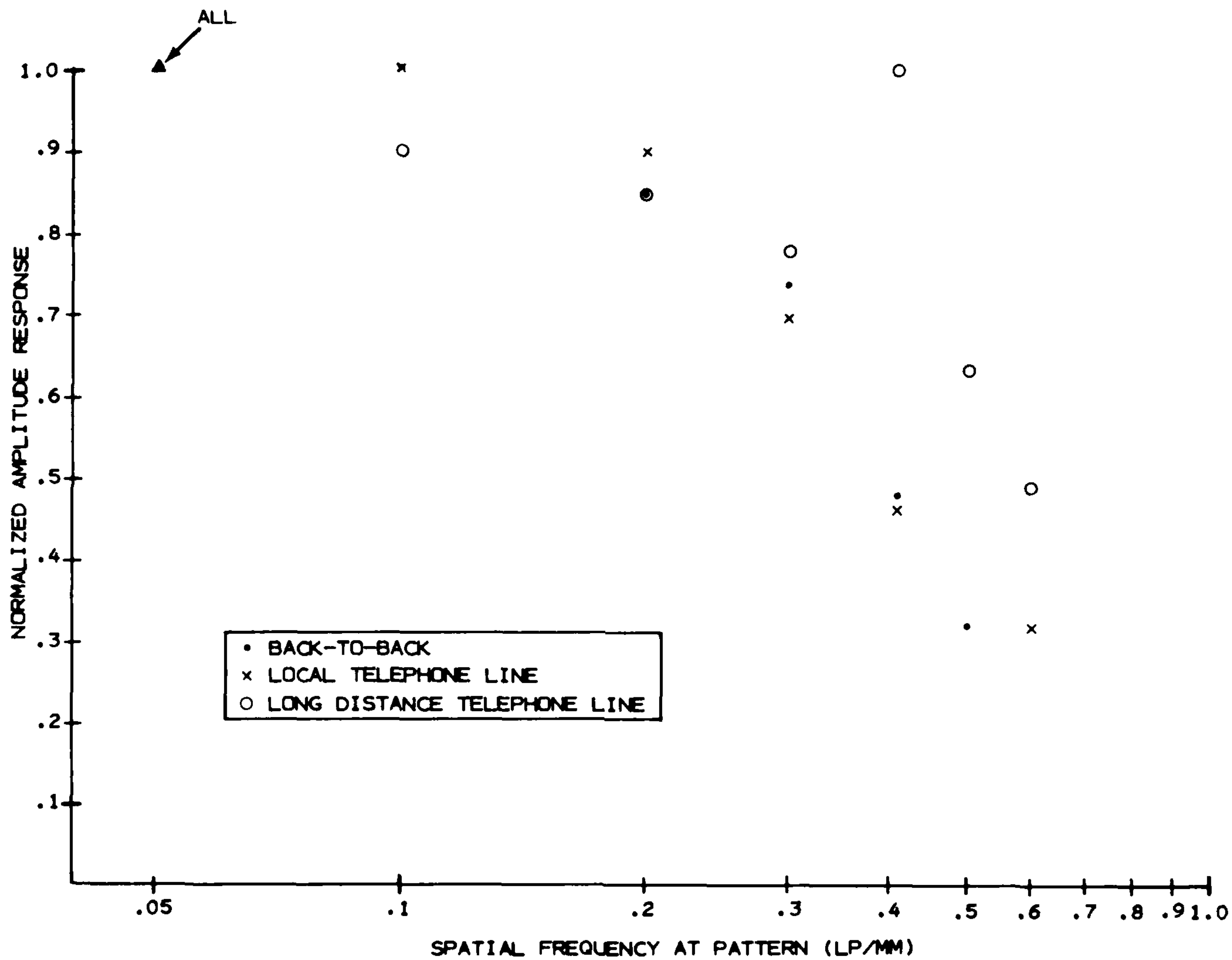


Figure 81. Normalized frequency response for center field, digital video transmission mode.

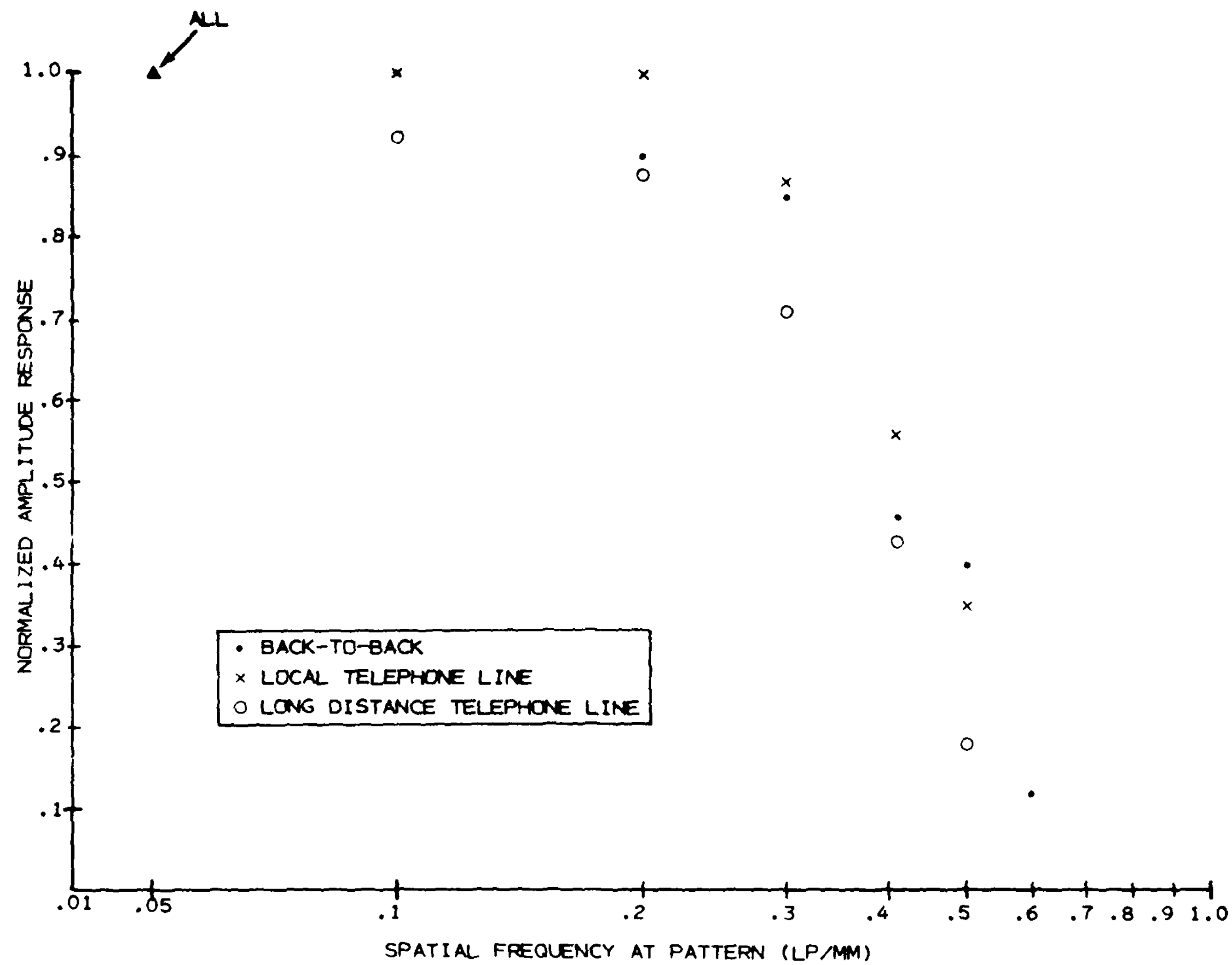


Figure 82. Normalized frequency response for corner field, digital video transmission mode.

image sources. The transmitting and receiving terminals were linked in a back-to-back communication configuration. Image signals were transmitted via the fine resolution mode at a 2400 bps rate.

Figure 83 shows representative photographs of the oscilloscope display used for resolution measurement. The same noise and ringing seen in the analog video transmission mode were present in the digital mode, and determining frequency response was similarly complicated. The reduced data from the photographs similar to figure 83 are listed in table 24 and plotted in figure 75.

The effects of ringing and the nominal data obtained from these tests made an estimation of any reasonable accuracy of the limiting resolution point inappropriate. Nonetheless, the 50% modulation resolution for the conditions tested were estimated and are listed below.

Image Source	Resolution (lp/mm)
TV Camera	0.53
Frame Freeze	0.46

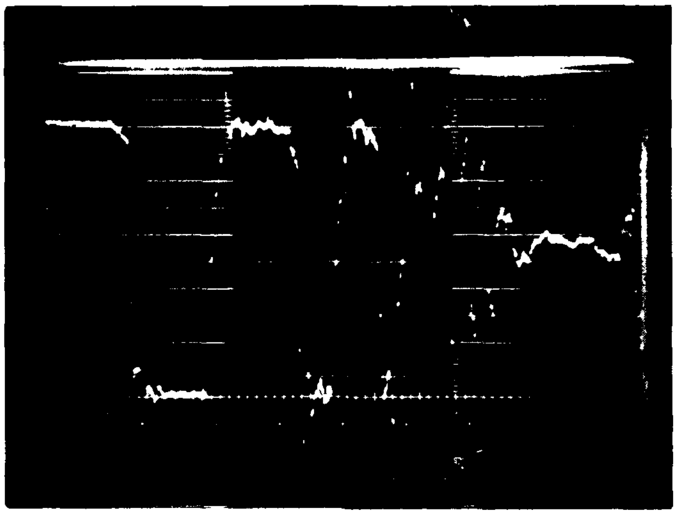
The above resolution measurements correspond to the values obtained for the CGM camera testing.

	Normalized Amplitude Center of Field	
Resolution (lp/mm)	Camera Image	Frame Freeze
0.05	1.00	1.00
0.10	1.00	0.98
0.20	0.87	0.83
0.30	0.83	0.78
0.41	0.80	0.65
0.50	0.56	0.33
0.60	0.32	

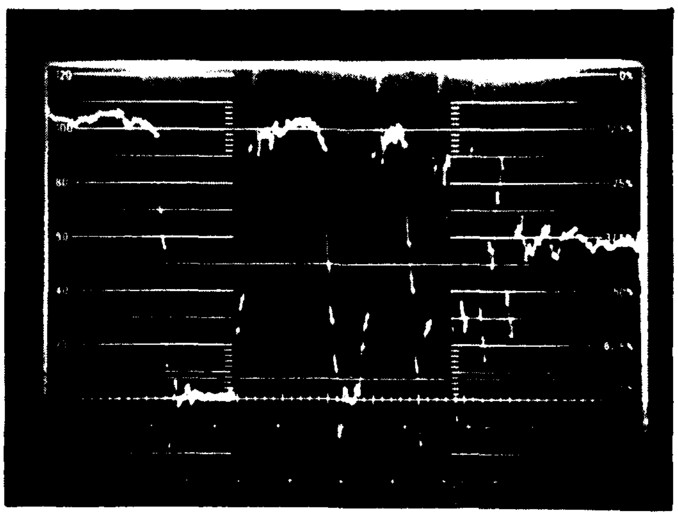
Table 24. Horizontal resolution test data for back-to-back communication link, 2400 bps digital video transmission (Cohu camera).

5.4 VERTICAL RESOLUTION MEASUREMENT

Vertical resolution tests were not performed during the original laboratory testing period because a Colorado Video, Inc. Model 321 Video Analyzer was not available. Vertical resolution testing was performed during the laboratory retesting period, when the 321 Video Analyzer became available.



(a) Camera



(b) Frame freeze

Figure 83. Horizontal resolution photographs for digital fine transmission, back-to-back, Cohu camera.

Figures 84 through 86 show the test patterns used for the vertical resolution testing. Additional measurements were obtained by zooming in on figure 86. The TV camera was first adjusted so that the 7-1/2 x 10 inch field of the test pattern just filled the total field being imaged. Next, the focus and brightness controls for the camera were adjusted to produce a visually optimum image display. The output of the video system under test was input to the video analyzer, which supplied a visual presentation on a TV monitor containing a signal amplitude scale for measurements. The cursor associated with the video analyzer was then centered in the row of horizontal lines to be tested. Polaroid photographs were taken of the TV monitor display, and average peak-to-peak waveform heights for each photograph were obtained. The data were normalized to the peak-to-peak amplitude versus the spatial frequency for the corresponding pattern cycle, resulting in a normalized square wave amplitude response curve. This is approximately equivalent to the modulation transfer function curve for the system being tested.

5.4.1 TV Camera/Lens System

The CGM TV camera/lens system were tested for vertical resolution by the procedure mentioned above. Figures 87 through 89 are representative samples of the photographs taken from the TV monitor which were used to obtain peak-to-peak amplitude measurements. The peak-to-peak normalized amplitudes versus line pair spatial frequencies for the TV camera response are listed in table 25 and plotted in figure 90.

Although the 10% modulation level cannot be directly obtained from figure 90, it was expected to lie at approximately 1.40 line pairs per mm. This corresponds to 530 TV lines per picture height. It should be noted that since the CGM and standard monochromic cameras provide 525 lines per frame in the vertical direction, the conditions tested met specifications for vertical resolution.

5.4.2 Frame Freeze (Video Disc Recorder)

Vertical resolution measurements were taken for the frame freeze system after image storage from the CGM camera. The peak-to-peak normalized amplitude measurements versus line pair spatial frequencies were obtained from photographs similar to figures 87 through 89. They are listed in table 26 and plotted in figure 91.

From figure 91, the 10% modulation level was expected to be approximately 1.30 line pairs per mm, which corresponds to 495 TV lines per picture height. The value obtained from frame freeze vertical resolution is somewhat less than that of the TV camera (530 TV lines per picture height). Nonetheless, frame freeze vertical resolution should be adequate for the RMDS terminals.

5.4.3 Analog Video Transmission

Testing was conducted for received vertical resolution response of images transmitted via the analog video mode. Listed below are the various conditions tested:

- Communication Link
- Coarse versus Fine Resolution Mode
- TV Camera versus Frame Freeze Image

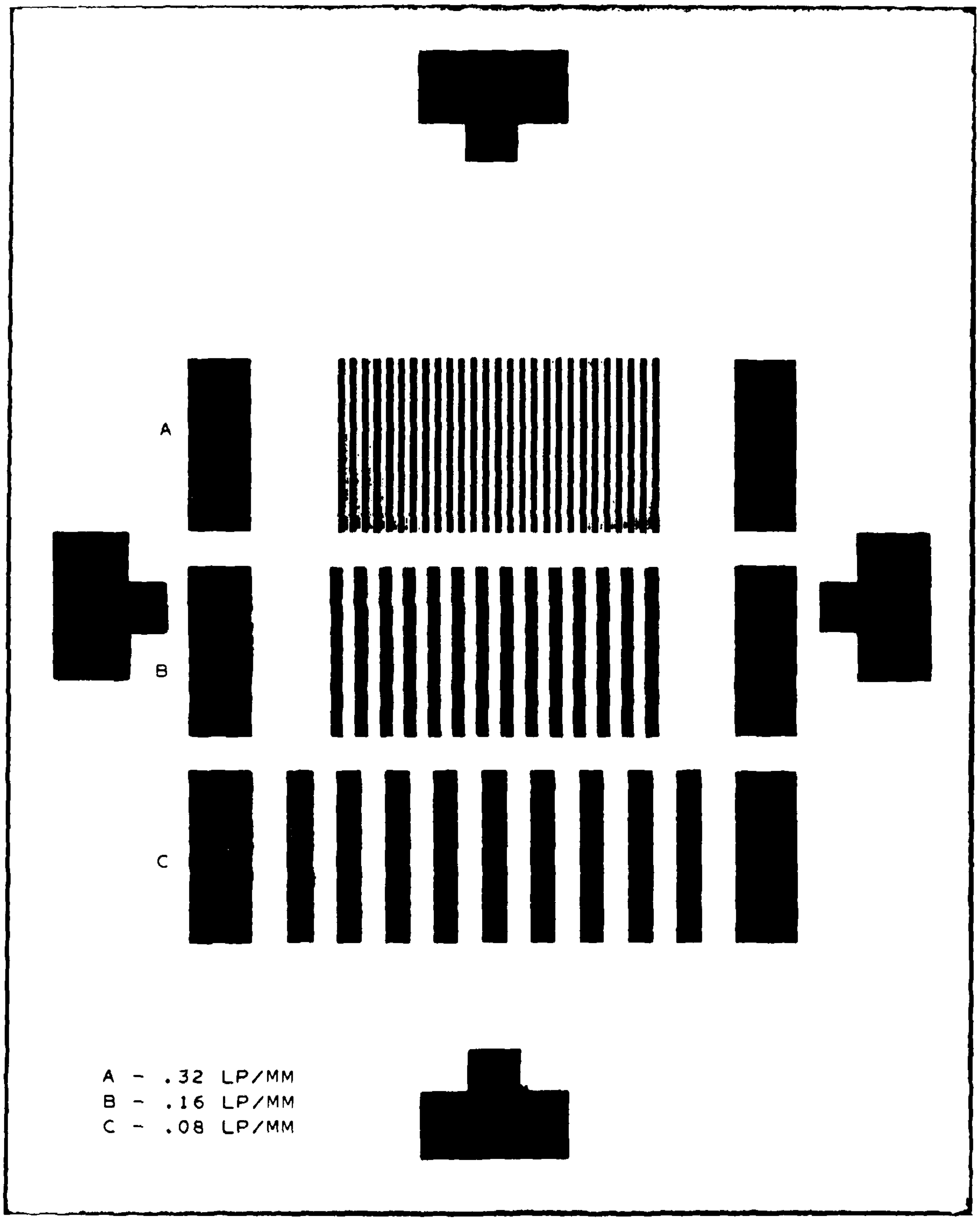


Figure 84. Vertical Resolution Test Pattern 1.

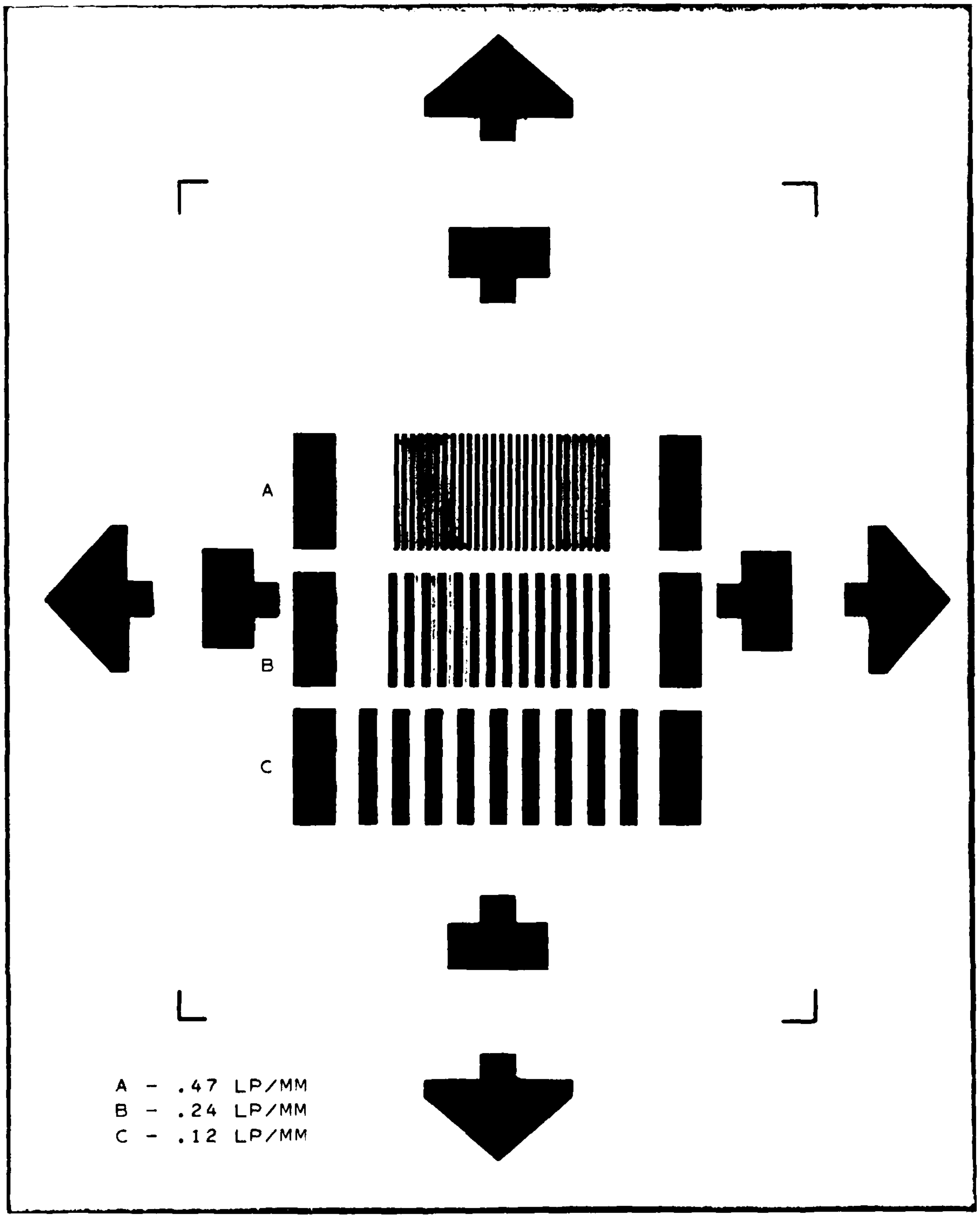


Figure 85. Vertical Resolution Test Pattern 2.

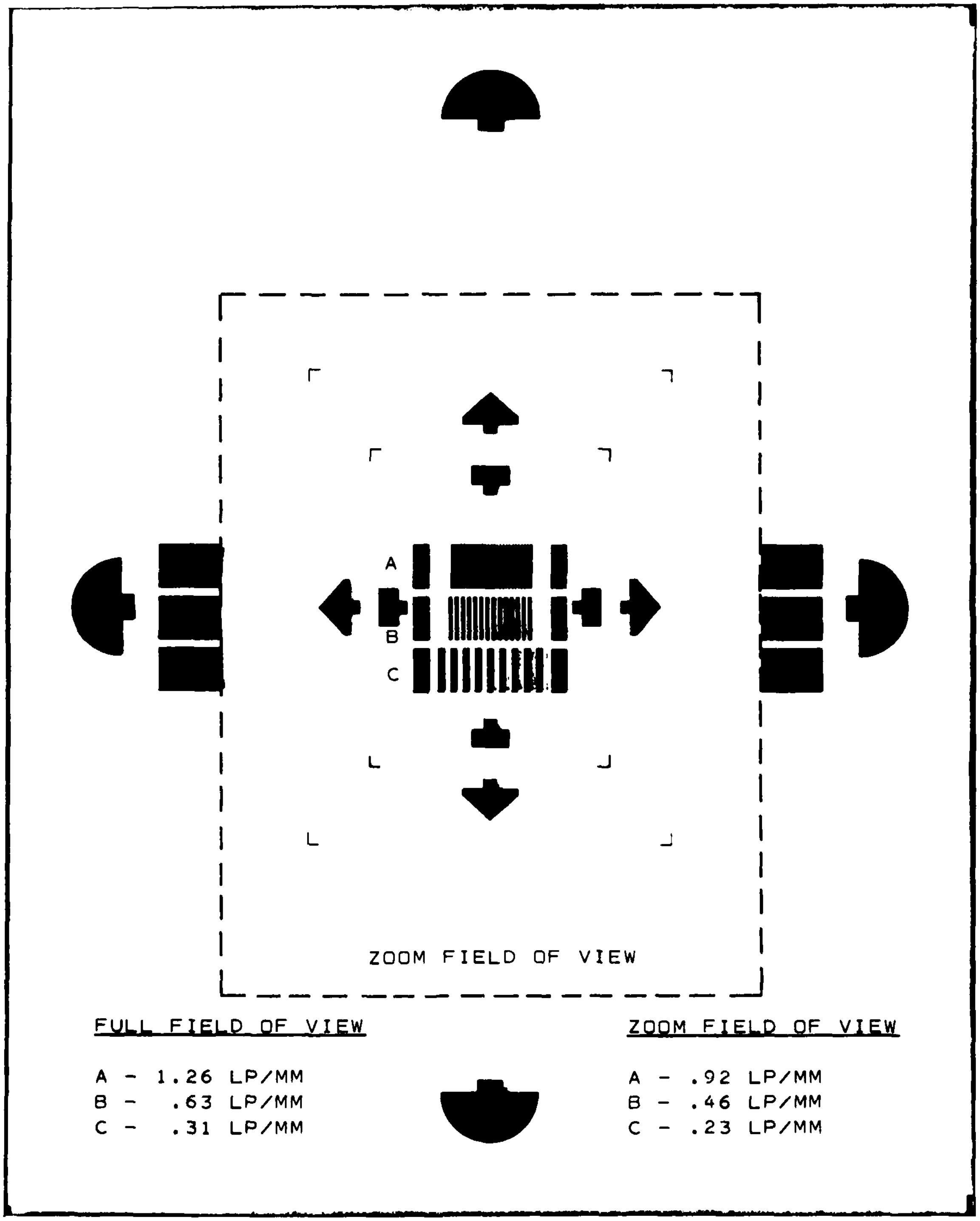


Figure 86. Vertical Resolution Test Pattern 3.

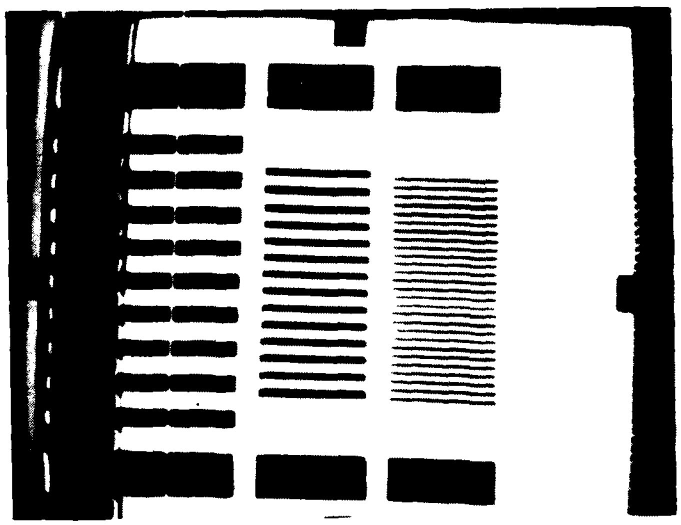


Figure 87. Vertical resolution photograph for digital fine transmission, back-to-back, Test Pattern 1.

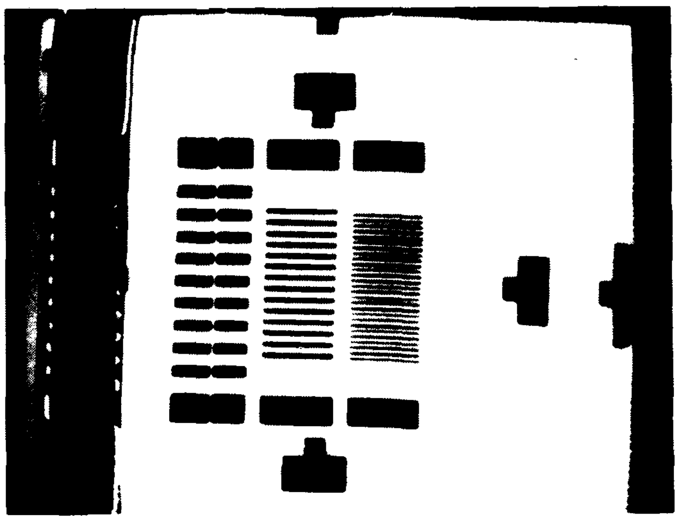
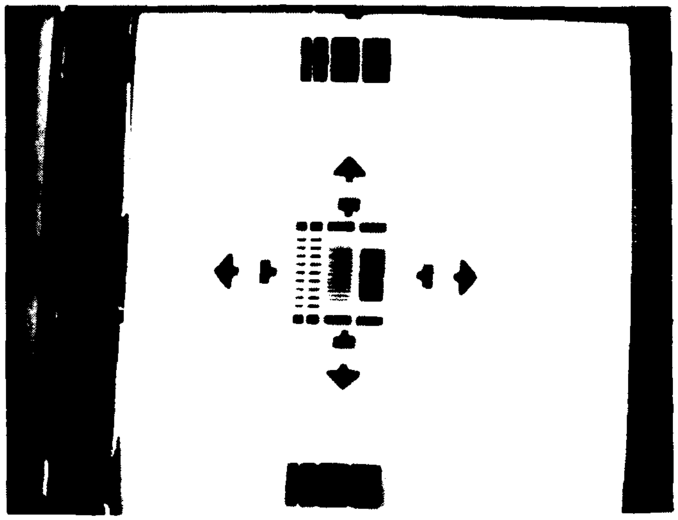
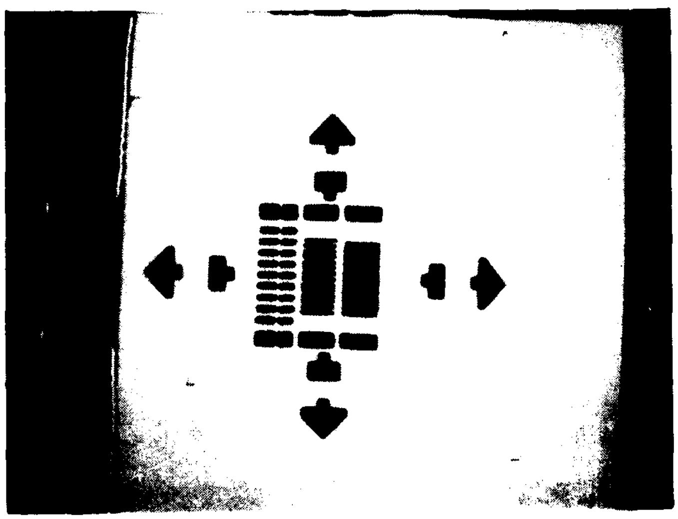


Figure 88. Vertical resolution photograph for digital fine transmission, back-to-back, Test Pattern 2.



(a) Normal



(b) Zoom

Figure 89. Vertical resolution photographs for digital fine transmission, back-to-back, Test Pattern 3.

Resolution (lp/mm)	Normalized Amplitude
0.08	1.00
0.12	0.98
0.16	0.96
0.23	0.93
0.24	0.88
0.31	0.85
0.32	0.87
0.46	0.71
0.47	0.73
0.63	0.51
0.92	0.30
1.26	0.16

Table 25. Vertical resolution test data for TV camera/lens system.

Resolution (lp/mm)	Normalized Amplitude
0.08	1.00
0.12	0.95
0.16	0.92
0.23	0.88
0.24	0.88
0.31	0.85
0.32	0.80
0.46	0.81
0.47	0.78
0.63	0.35
0.92	0.21
1.26	0.11

Table 26. Vertical resolution test data for frame freeze.

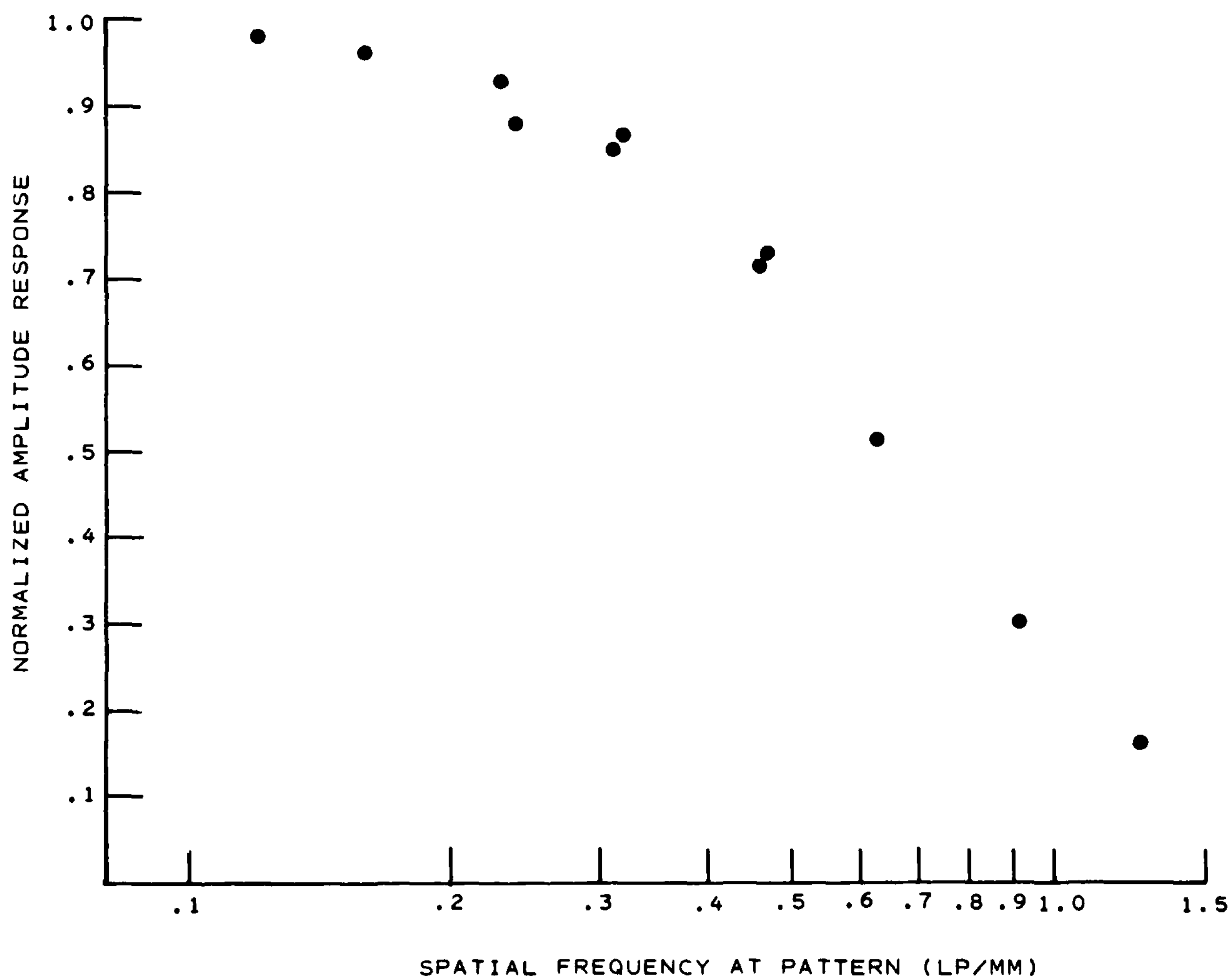


Figure 90. Vertical resolution normalized frequency response for TV camera/lens system.

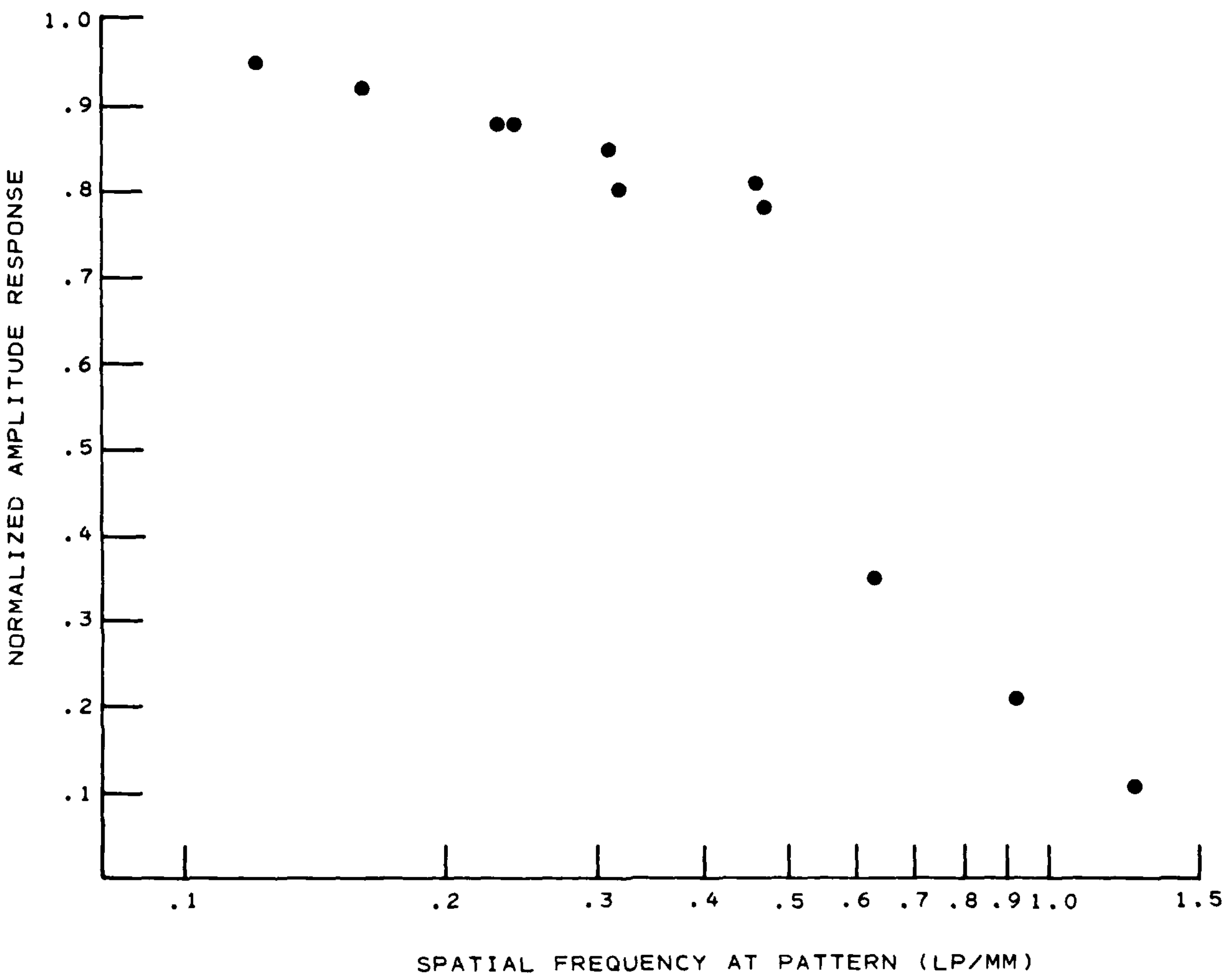


Figure 91. Vertical resolution normalized frequency response for frame freeze.

The peak-to-peak normalized amplitude measurements versus line pair spatial frequencies for the conditions tested are listed in tables 27 and 28 and plotted in figures 92 through 94.

A comparison of coarse and fine resolution in figure 92 indicated better response for the fine mode. The 10% modulation level for the fine mode is approximately 1.1 line pairs per mm, whereas the coarse is considerably less, approximately 0.7 line pair per mm. These values correspond to 420 and 270 TV lines per picture height, respectively.

As can be seen in figures 93 and 94, the curves of frequency response for all conditions tested, except back-to-back coarse as mentioned above, were similar in shape and transverse the area of the 25% modulation level in the range of 0.5 to 0.6 line pair per mm. These correspond to approximately 190 and 230 TV lines per picture height, respectively. It was expected that the 10% modulation level of the other conditions tested would be similar to that of the back-to-back camera fine image (420 TV lines per picture height).

5.4.4 Digital Video Transmission

Testing was conducted for received vertical resolution response of images transmitted via the digital video mode. Listed below are the various conditions tested:

- Communication Link
- Coarse versus Fine Resolution Mode
- Camera versus Frame Freeze Image

The peak-to-peak normalized amplitude measurements versus line pair spatial frequencies for the conditions tested are listed in tables 29 and 30 and plotted in figures 95 through 97.

As can be seen in figures 95 through 97, the curves of frequency response for the conditions tested were similar in shape and transversed the area of the 25% modulation level in the range of 0.9 to 1.0 line pair per mm (340 and 380 TV lines per picture height, respectively). Two exceptions to this are 1) back-to-back camera, coarse and 2) long distance telephone camera, fine. These cross at approximately 0.62 and 0.48 line pair per mm, respectively (240 and 180 TV lines per picture height). As in the analog transmission mode, the fine resolution mode provided better vertical resolution than coarse. A comparison of vertical resolution for analog and digital transmission modes indicated better response for the digital mode.

5.5 FLATNESS OF FIELD

Testing was conducted to determine the uniformity of the signal level over the TV camera field of view for a flat input scene (uniform visual presentation). Test conditions were as follows:

Resolution (lp/mm)	Normalized Amplitude Camera Coarse	Camera Fine	Frame Freeze Fine
0.08	1.00	1.00	1.00
0.12	1.00	0.98	0.92
0.16	0.98	0.96	0.92
0.23		0.90	0.90
0.24	0.89	0.88	0.89
0.31	0.86	0.78	0.56
0.32	0.72	0.74	0.72
0.46		0.33	0.36
0.47	0.39	0.39	0.36
0.63	0.06	0.17	0.21
0.93		0.15	0.18
1.26		0.06	0.11

Table 27. Vertical resolution test data for back-to-back communication link of analog video transmission mode.

	Normalized Amplitude			
	Local		Long Distance	
Resolution (lp/mm)	Camera	Frame Freeze	Camera	Frame Freeze
0.08	1.00	1.00	1.00	1.00
0.12	0.98	0.99	0.95	0.97
0.16	0.97	0.98	0.92	0.95
0.23	0.96	0.95	0.88	0.86
0.24	0.94	0.95	0.82	0.90
0.31	0.84	0.88	0.80	0.73
0.32	0.79	0.89	0.70	0.68
0.46	0.36	0.36	0.29	0.29
0.47	0.37	0.32	0.26	0.30
0.63	0.18	0.18	0.21	0.21
0.92	0.19	0.19	0.18	0.19

Table 28. Vertical resolution test data for local and long distance telephone communication links of analog video transmission mode (fine).

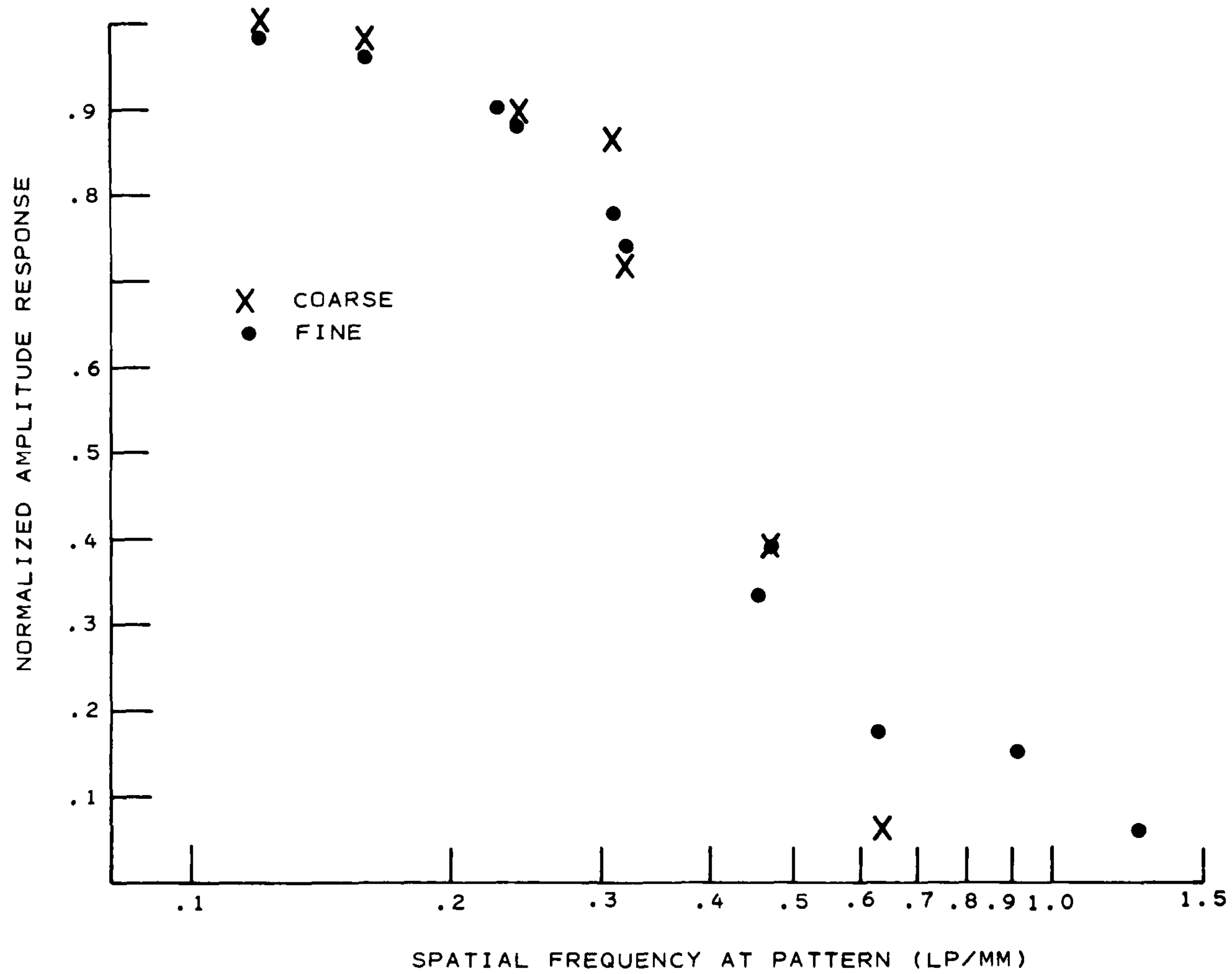


Figure 92. Vertical resolution normalized frequency response for analog video transmission, camera image, back-to-back.

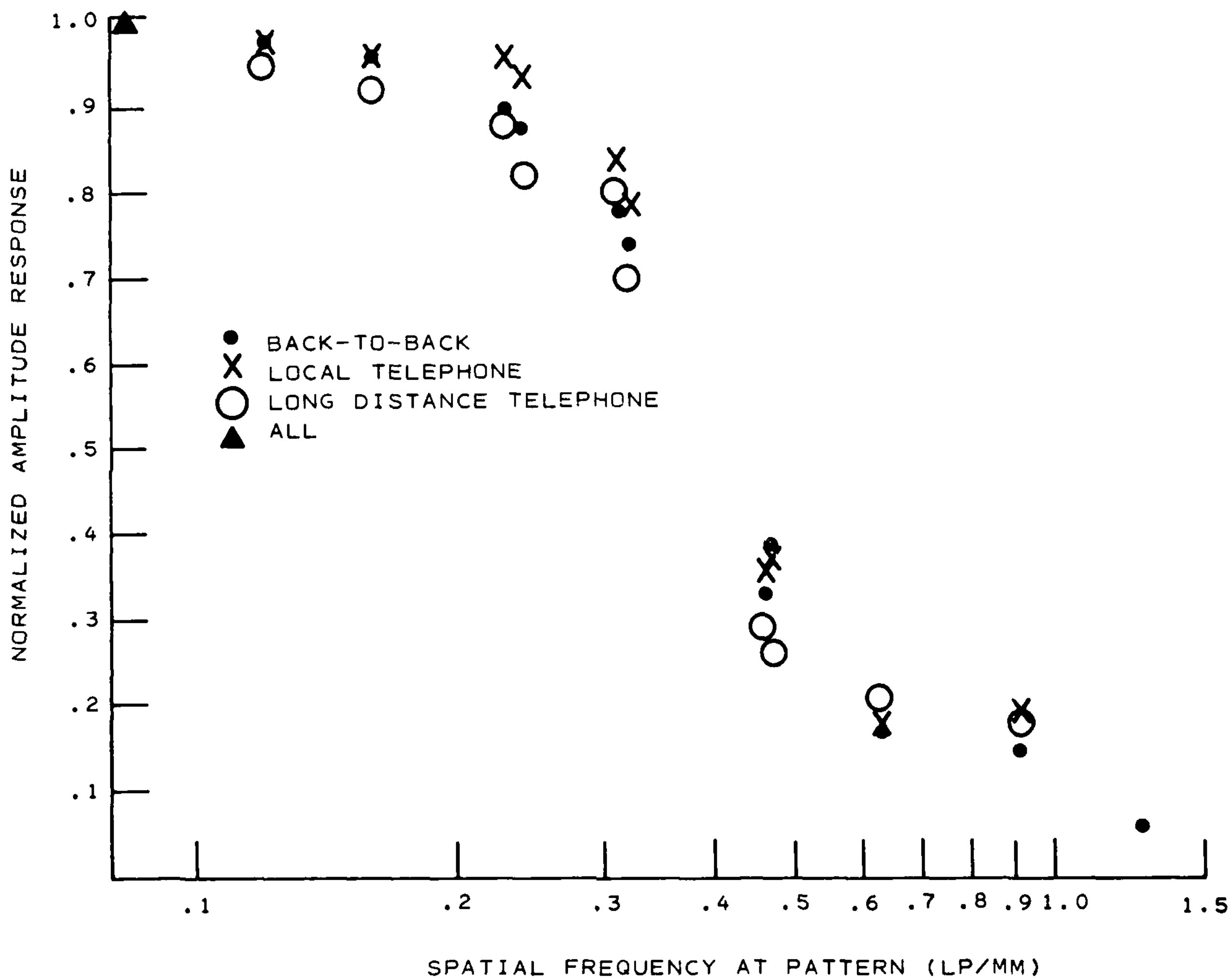


Figure 93. Vertical resolution normalized frequency response for analog video transmission, fine, camera image.

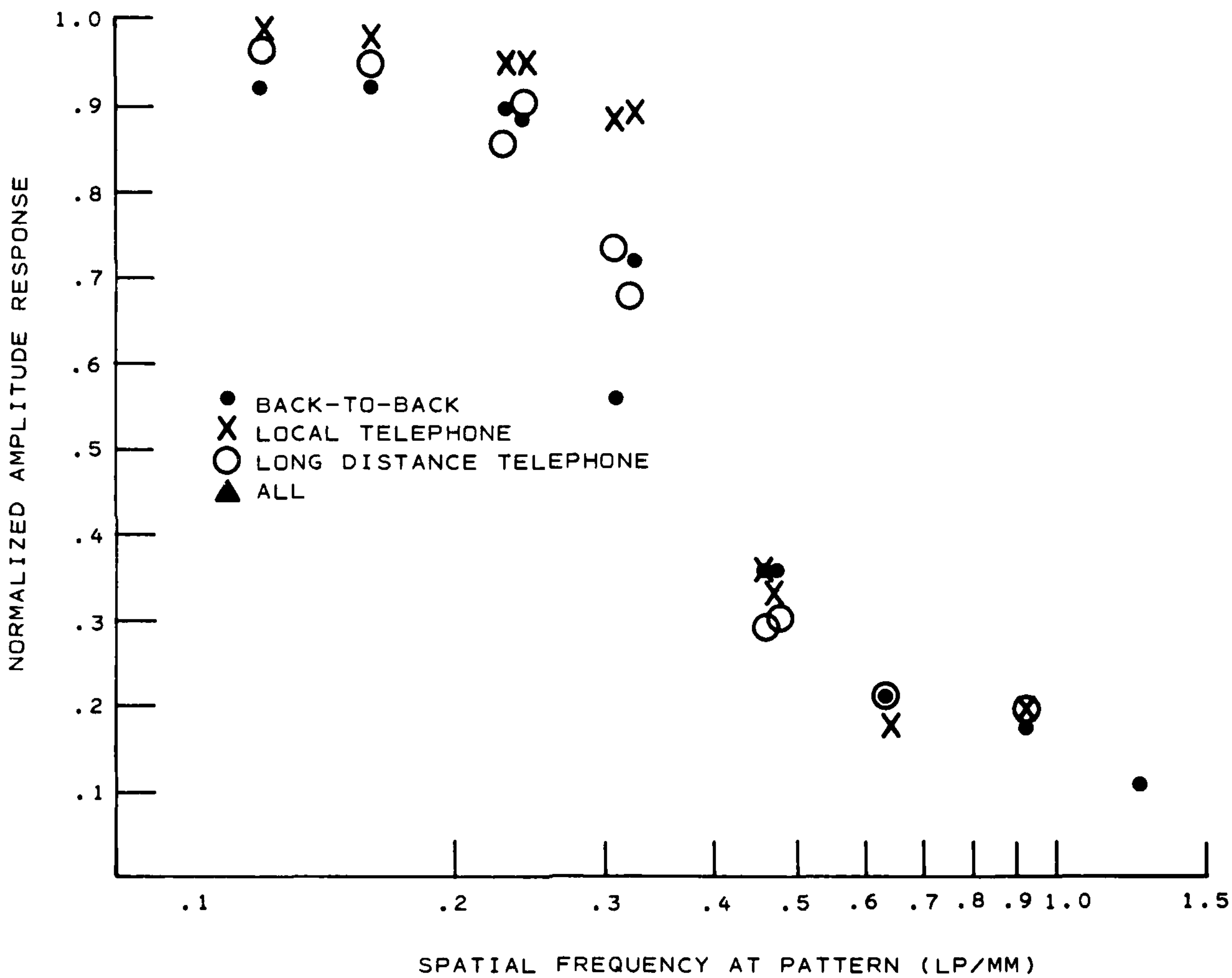


Figure 94. Vertical resolution normalized frequency response for analog video transmission, fine, frame freeze image.

Resolution (lp/mm)	Normalized Amplitude Camera Coarse	Camera Fine	Frame Freeze Fine
0.08	1.00	1.00	1.00
0.12	0.94	0.98	0.98
0.16	0.95	0.95	0.97
0.23		0.93	0.95
0.24	0.95	0.94	0.92
0.31	0.86	0.88	0.91
0.32	0.92	0.92	0.91
0.46		0.80	0.78
0.47	0.80	0.80	0.77
0.63	0.22	0.45	0.70
0.93		0.30	0.24
1.26		0.07	0.17

Table 29. Vertical resolution test data for back-to-back communication link of digital video transmission mode.

	Normalized Amplitude			
	Local		Long Distance	
Resolution (lp/mm)	Camera	Frame Freeze	Camera	Frame Freeze
0.08	1.00	1.00	1.00	1.00
0.12	0.99	0.99	1.00	0.98
0.16	0.97	0.98	1.00	0.89
0.23	0.95	0.90	0.94	0.89
0.24	0.94	0.90	0.93	0.90
0.31	0.90	0.90	0.90	0.89
0.32	0.92	0.89	0.91	0.90
0.46	0.79	0.73	0.78	0.78
0.63	0.57	0.59	0.62	0.64
0.92	0.19	0.18	0.23	0.26
1.26	0.11	0.07	0.10	0.11

Table 30. Vertical resolution test data for local and long distance telephone line communication links of digital video transmission mode (fine).

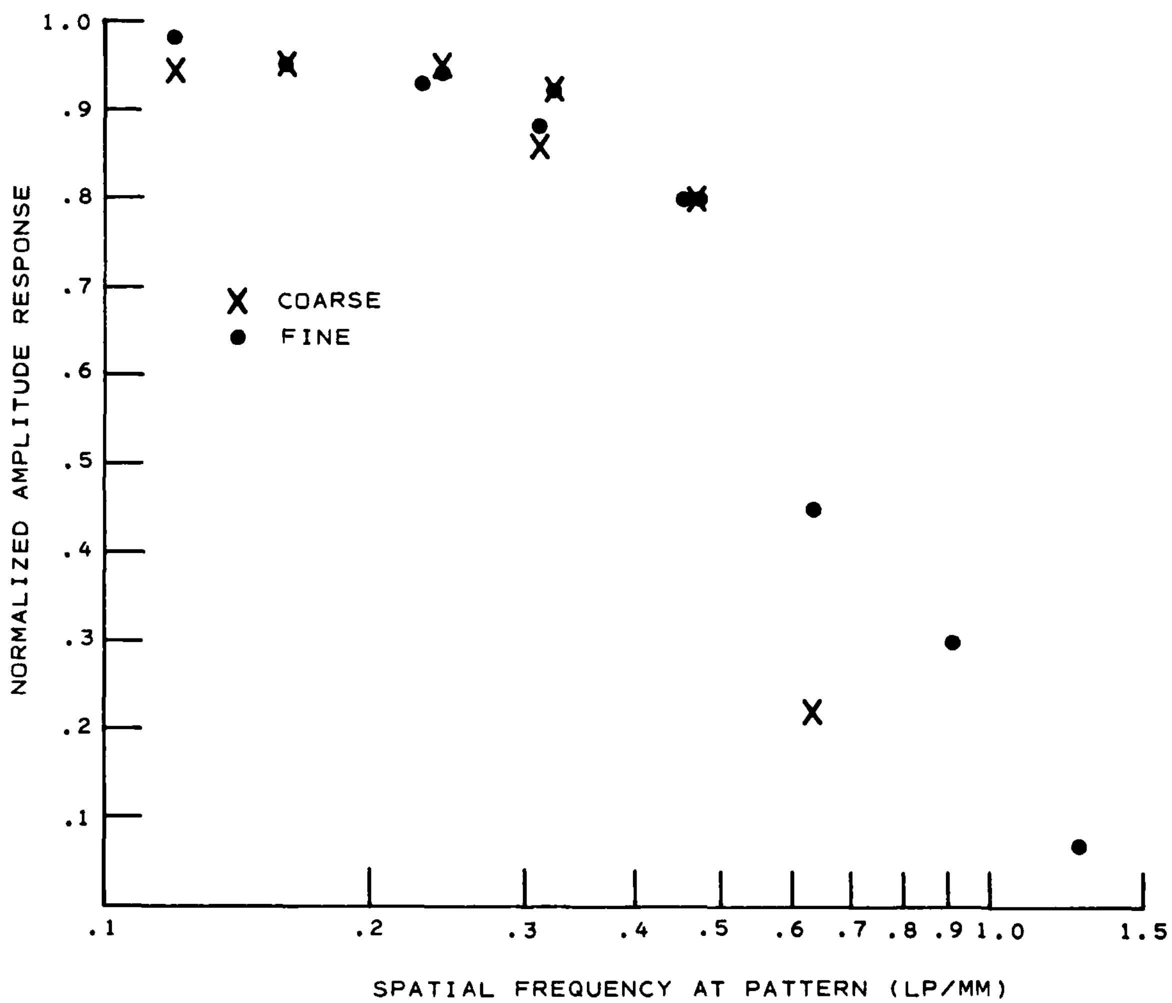


Figure 95. Vertical resolution normalized frequency response for digital video transmission, camera image, back-to-back.

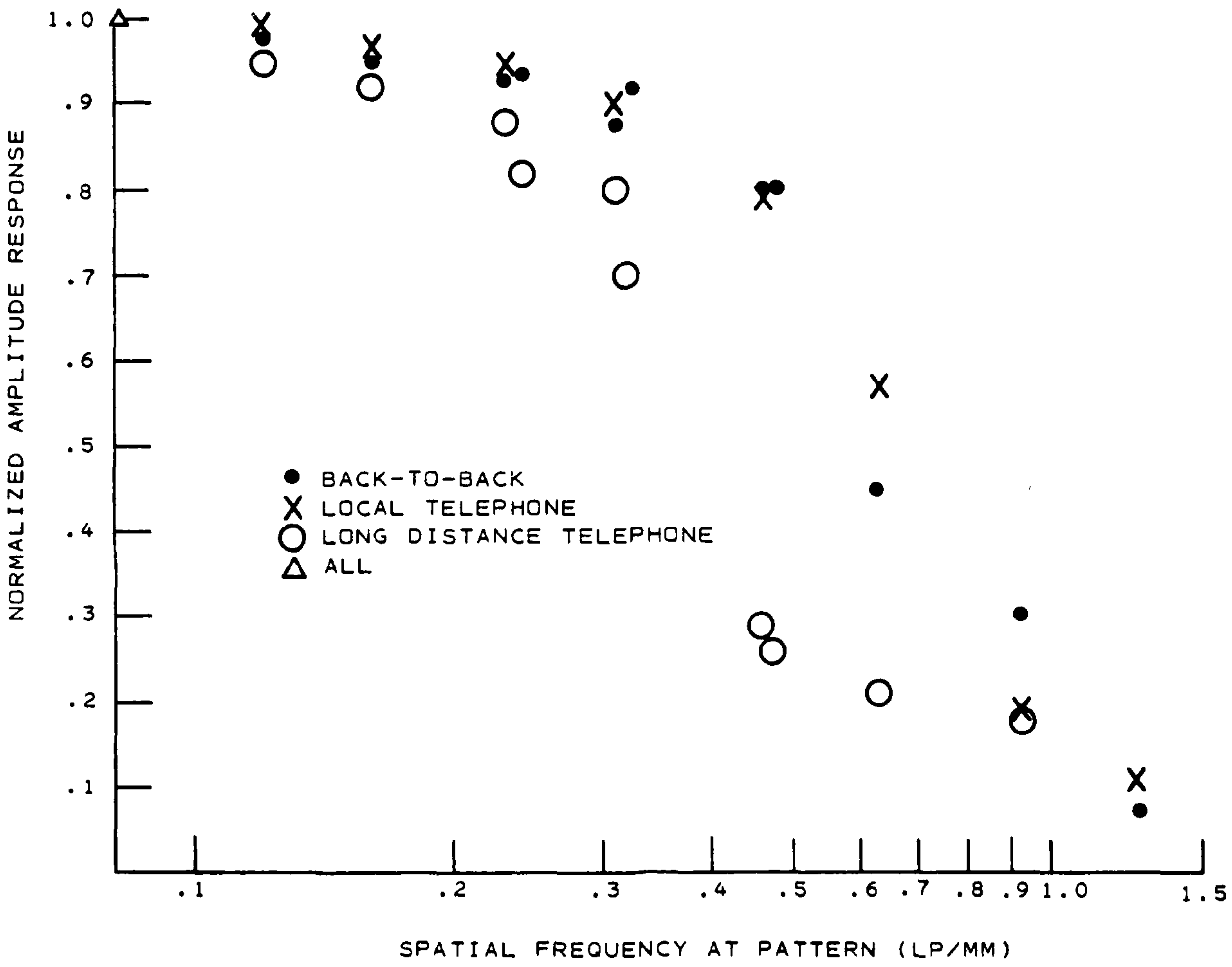


Figure 96. Vertical resolution normalized frequency response for digital video transmission, fine, camera image.

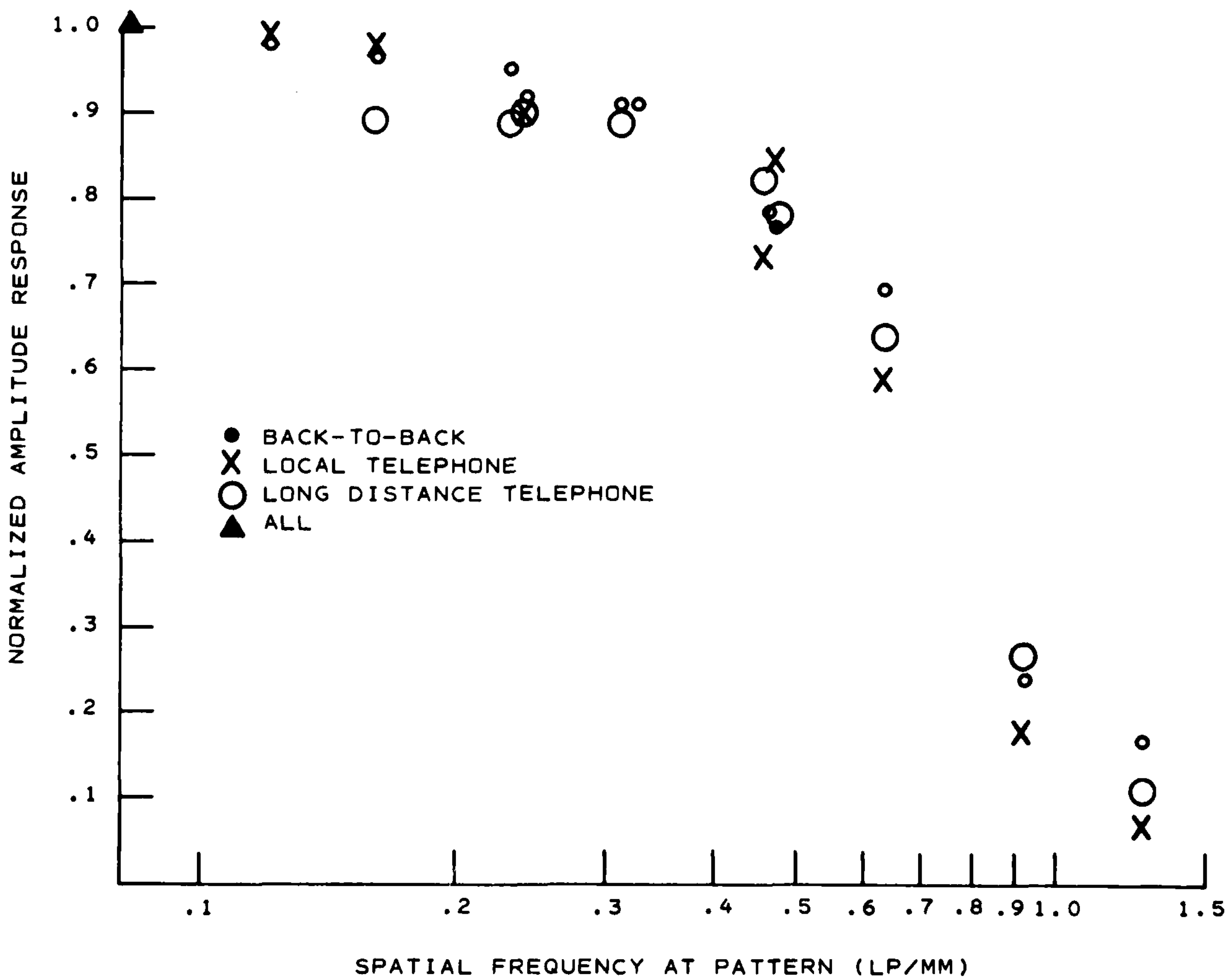


Figure 97. Vertical resolution normalized frequency response for digital video transmission, fine, frame freeze image.

- 24-1/2" pattern-to-lens distance, 7-1/2" x 10" field of view
- 24-1/2" pattern-to-lens distance, maximum field of view
- 24-1/2" pattern-to-lens distance, 7-1/2" x 10" field of view with a 1.0 optical density (OD) filter

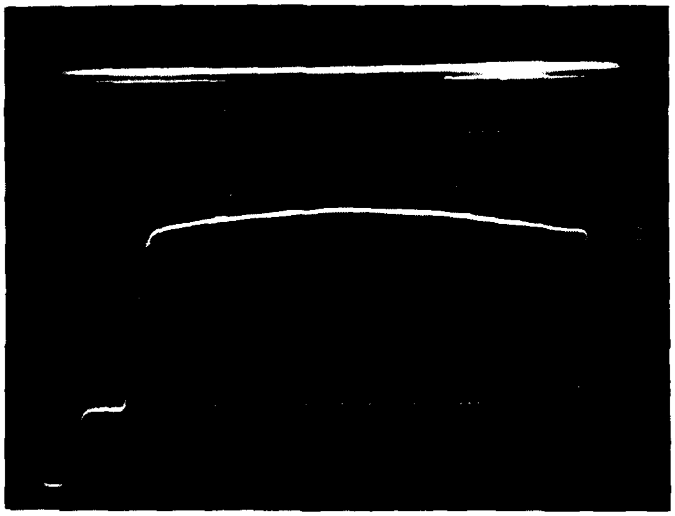
The RMDS transmit/receive terminals were set up for video use. The TV camera to viewbox distance was set for 24-1/2 inches. The Resolution Measurement Test Pattern, figure 58, was used to set the TV camera and monitor presentation to an optimum image quality. The WIDE ANGLE TELEPHOTO control was set at either 7-1/2" x 10" or maximum field of view, depending on the conditions under test. The Resolution Measurement Test Pattern was then removed so that the TV camera viewed an empty field. An oscilloscope was connected to the TV camera output and synchronized to the vertical field rate. Through the use of the delayed sweep feature of the oscilloscope, a single horizontal line of video was displayed at 5, 10, 15, 20, and 25 milliseconds after the vertical sync pulse occurred. This gave a series of horizontal lines of video from top to bottom on the TV monitor. A 500 kHz low pass filter was used to eliminate high frequency camera signals without distorting flatness measurements. Photographs of the oscilloscope display were analyzed for flatness of field.

Figure 98 shows representative photographs taken in the above method. Table 31 lists the normalized amplitudes per test condition of each photograph at points A through E indicated on figure 99, which correspond to horizontal positions on the TV monitor from left to right, respectively.

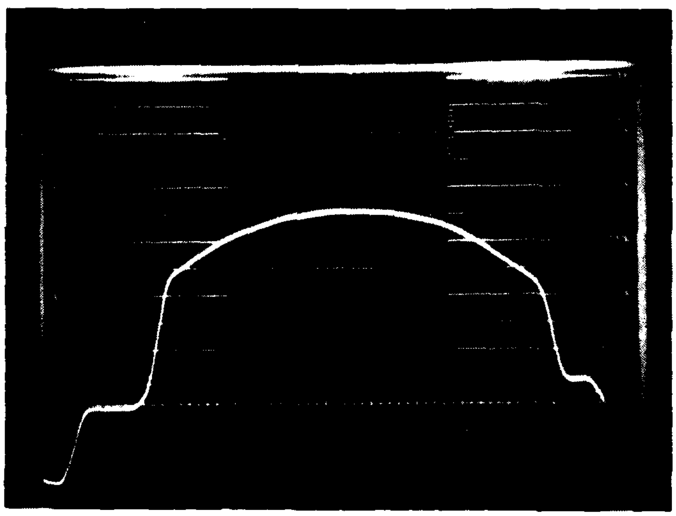
A plot of the normalized amplitudes for the 7-1/2" x 10" field of view without the filter is given in figure 100. Degradation of flatness of field was observed in both horizontal and vertical directions. Decreases in horizontal flatness of field were indicated by amplitude roll-off for each of the horizontal lines at 5, 10, 15, 20, and 25 millisecond delays. Similar roll-off was observed for each sync time, with a decrease in amplitude as the left (point A) and right (point E) edges of the TV monitor (see figure 100) are approached.

Variations in vertical flatness of field were indicated by the vertical position of the 5, 10, 15, 20, and 25 millisecond delay line on figure 100. Flatness of field decreased as the camera vertically approached the middle from either the top or bottom of the TV monitor; ie, the general amplitudes of the delay line where $5 > 10 > 15 < 20 < 25$. It should be noted that the lighting arrangement within the viewbox consisted of two fluorescent lights dividing the viewbox width into thirds. This accounted for the decreased signal amplitude in the middle of the TV monitor, since the upper and lower edges of the field of view were physically close to the lighting source of the viewbox.

Figure 101 is a graph of the 15 ms sync delay for the three conditions tested. It can be seen from this graph that the flatness of field decreased 1) with the transition from 7-1/2" x 10" to maximum field of view and 2) when the 1.0 optical density filter was used. To compensate for the addition of the 1.0 OD filter, the aperture of the camera was opened further to maintain a constant signal level. This increased the area at the perimeter of the lens being used to view the field. With most lenses, the distortion to flatness increases with increased aperture; a similar effect was observed for the above condition.



(a) 7-1/2" x 10" field of view

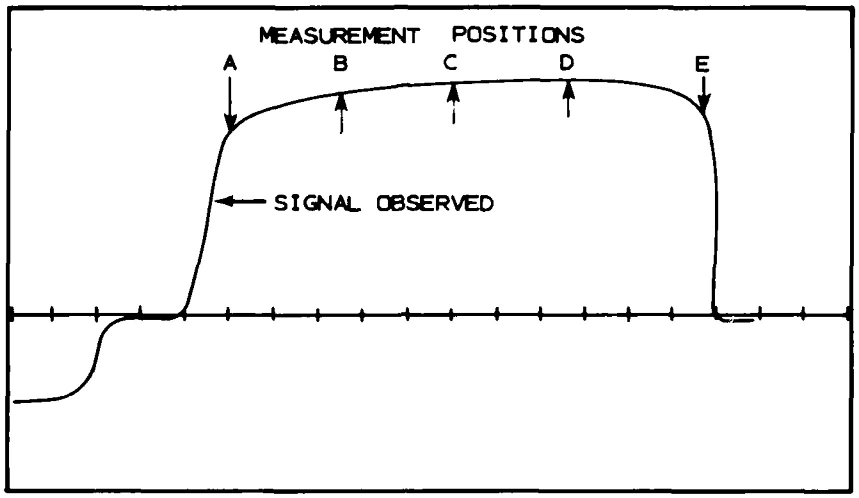


(b) Maximum field of view

Figure 98. Flatness of field photographs for horizontal line, 15 ms delay.

	DELAY (MS)	POINT A (LEFT EDGE)	B	C (CENTER)	D	E (RIGHT EDGE)
7¼" X 10" FIELD OF VIEW	5	.90	1.00	1.00	.97	.92
	10	.82	.91	.95	.91	.83
	15	.81	.90	.92	.88	.79
	20	.83	.92	.95	.90	.83
	25	.87	.96	.96	.95	.90
7¼" X 10" FIELD OF VIEW PLUS O.D. FILTER	5	.88	1.00	1.00	.96	.85
	10	.82	.91	.94	.90	.78
	15	.78	.90	.91	.88	.77
	20	.82	.90	.94	.90	.81
	25	.85	.92	.96	.92	.86
MAXIMUM FIELD OF VIEW	5	.62	.78	.82	.77	.54
	10	.65	.92	.97	.91	.55
	15	.94	.91	.96	.89	.58
	20	.66	.92	1.00	.93	.61
	25	.61	.88	.93	.88	.58

Table 31. Summary of Flatness of Field Normalized Amplitude Measurements.



OSCILLOSCOPE PRESENTATION

Figure 99. Flatness of field measurement positions.

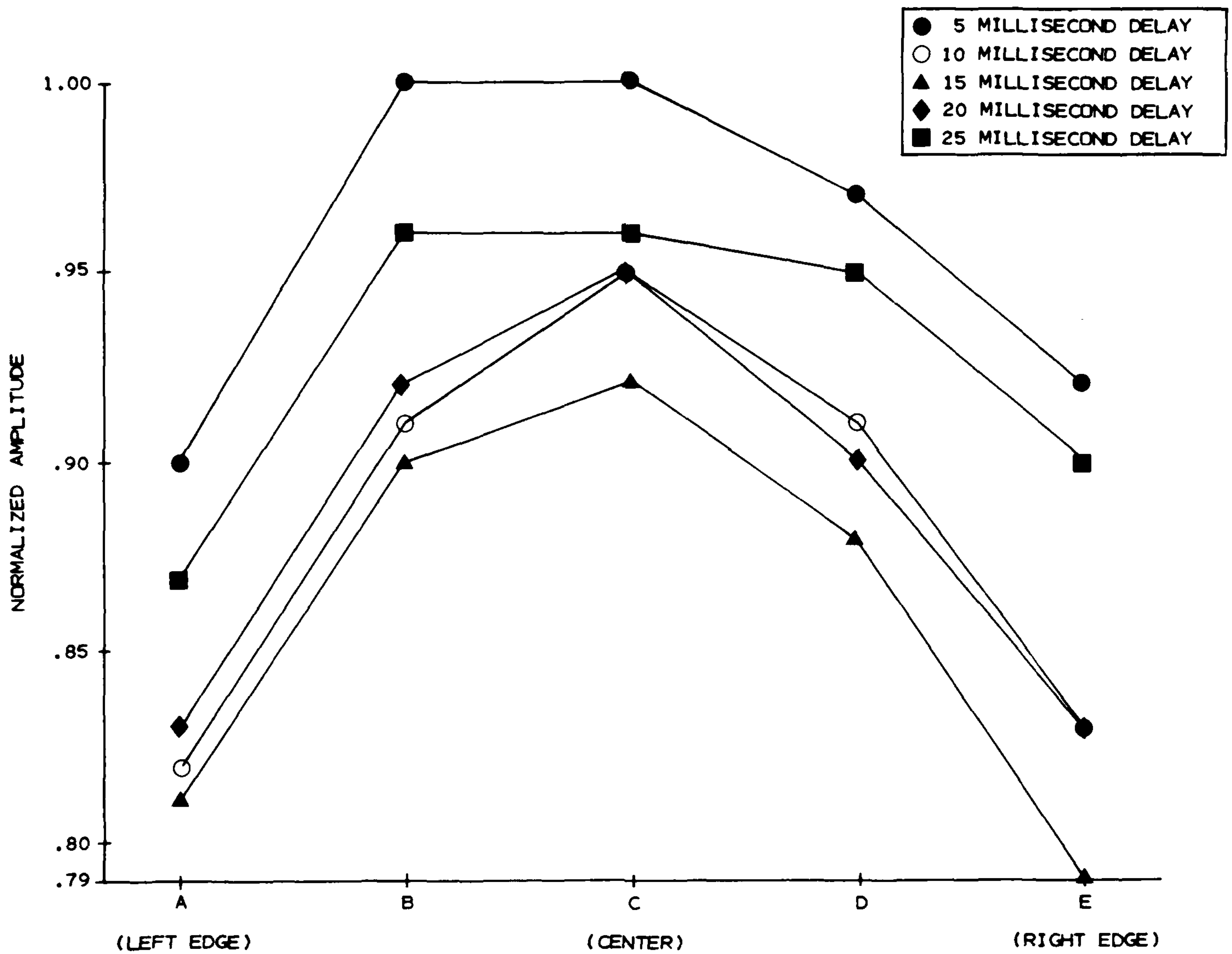


Figure 100 Comparison of flatness of field for 7-1/2" x 10" field of view at various delay times.

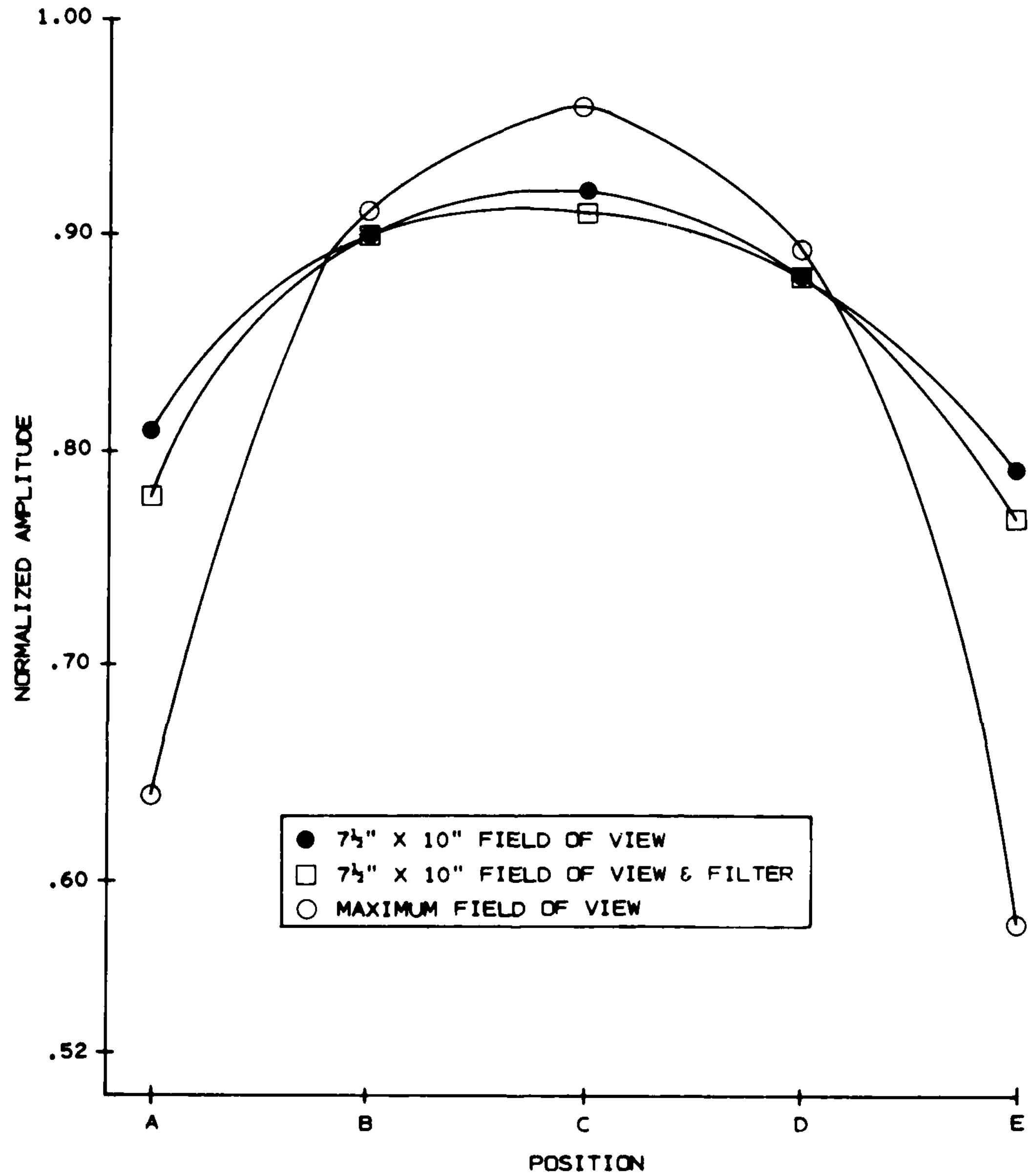


Figure 101. Comparison of flatness of field for 15 ms delay horizontal line for various fields of view.

The general specification calls for flatness of field to lie within 10% when viewing a uniformly illuminated field. At first glance the data obtained in this test would indicate that the TV camera/lens system does not meet this specification, with a decrease in signal of over 20% for the 7-1/2" x 10" field of view and over 40% for the maximum field of view (14" x 17"). It should be noted, however, that the camera was not viewing a uniformly illuminated field, as indicated in section 5.2 (Viewbox Lighting Uniformity). The decrease in flatness of field can be directly related to the decrease in lighting uniformity of the viewbox. A large part of the decreased flatness of field observed when comparing 7-1/2" x 10" field of view to the maximum field of view (14" x 17") can be attributed to the decrease in lighting uniformity observed at the edges of the viewbox. A more accurate value for flatness of field would be obtained by subtracting the distortion caused by the viewbox. As indicated earlier, an effort should be made to improve the light uniformity of the viewbox, which would also improve flatness of field.

5.6 GEOMETRIC LINEARITY

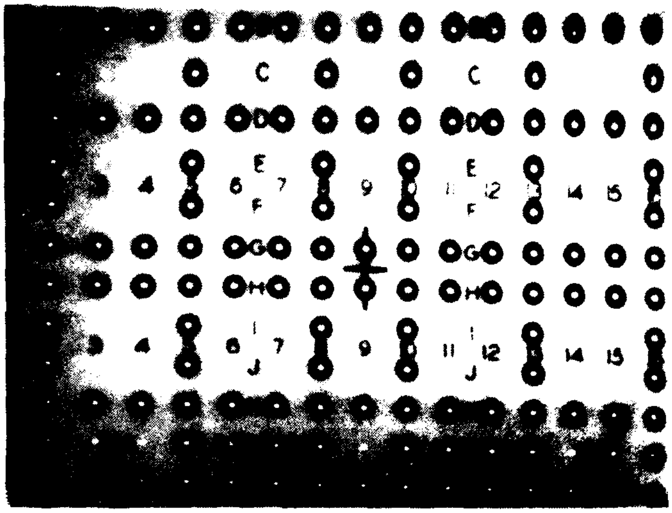
Tests were conducted to measure the geometric linearity of the TV camera. The RMDS terminal was set up for video use with the main TV camera. A precision EIA linearity chart was placed in the field of view of the TV camera and positioned to fill it entirely. Then a precision dot pattern was electronically added to the TV monitor. The dot pattern generated a precise matrix of dots, which was displayed against the matrix of annulets of the EIA test pattern. The TV camera and monitor were set for an optimum image quality. An oscilloscope was used to view a single horizontal line corresponding to a row of annulets on the test pattern. Photographs were taken of the oscilloscope display and analyzed for geometric linearity.

Figure 102 shows a photograph of the EIA linearity chart as it appeared on the TV monitor and a photograph of the oscilloscope display for row G of the EIA chart. Table 32 shows the displacement in mm of each annulet from the first annulet of each row as measured on the photograph. All seven rows tested (rows A, B, D, G, K, M, N) were very close in displacement measurement and did not vary over 1.6% from each other. The normalized values of row G were plotted in figure 103 and showed a linear transition from left to right across a horizontal line.

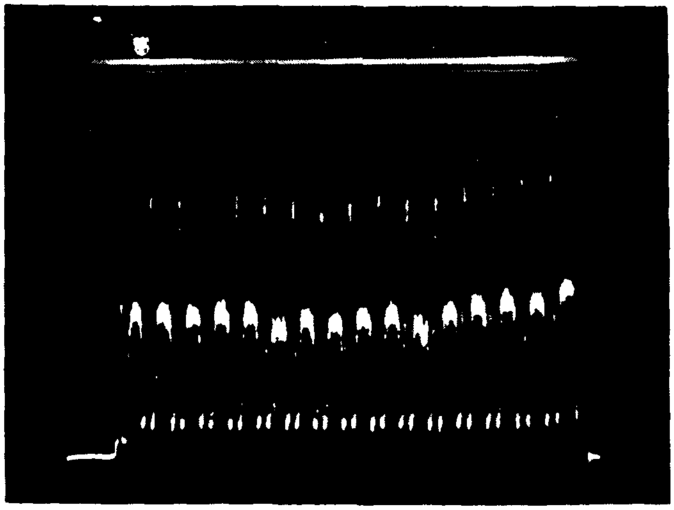
Another method to evaluate geometric linearity is to observe the position of the bright white dot on the test pattern (figure 102). If all the white dots fall within the black circle (annulet), the TV camera is said to be within 2% linearity. This method also showed the TV camera to be within 2% linearity.

5.7 SIGNAL-TO-NOISE LEVEL IN IMAGE TRANSMISSION

Testing was done to determine the signal-to-noise ratio (SNR) for video image transfer systems. The RMDS terminals were set up for video transmission of the system under test. The Resolution Measurement Test Pattern was used to set the TV camera for an optimum image presentation. The test pattern was then removed from the viewbox to transmit a blank image. The BRIGHTER-DARKER control was set at its electrical midpoint to display an image of moderate brightness on the TV monitor. An oscilloscope was used to measure the RMS noise level of the white video signal in a single horizontal line through the approximate middle of the image.



(a) ELA linearity chart as seen on TV monitor



(b) Oscilloscope display of Row G from
ELA linearity chart

Figure 102. Geometric linearity photographs.

ANNULET NUMBER

ROWS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A	0	4.5	9.0	13.0	17.0	21.0	25.0	29.0	33.0	37.0	41.0	45.5	49.5	53.8	58.0	62.0
B	0	4.5	8.8	12.8	16.5	21.5	24.5	28.5	32.8	36.8	41.0	45.0	49.2	53.2	57.8	61.8
D	0	4.5	8.5	12.8	16.8	20.5	24.5	28.8	32.8	36.8	41.0	45.0	49.2	53.5	57.5	62.0
G	0	4.5	8.5	12.5	16.5	20.5	24.5	28.5	32.5	36.5	41.0	45.0	49.2	53.5	57.5	61.8
K	0	4.8	9.0	12.8	17.0	21.0	25.0	28.8	33.0	37.0	41.2	45.5	49.5	53.5	57.8	62.2
M	0	4.2	8.2	12.2	16.5	20.5	24.5	28.5	32.5	36.8	41.0	45.0	49.2	53.5	57.5	61.5
N	0	4.5	8.8	12.8	16.8	20.8	25.0	28.8	32.8	37.0	41.2	45.2	49.5	53.5	57.2	61.5

Table 32. Geometric linearity measurements of displacement in mm of each annulet from first annulet of each row.

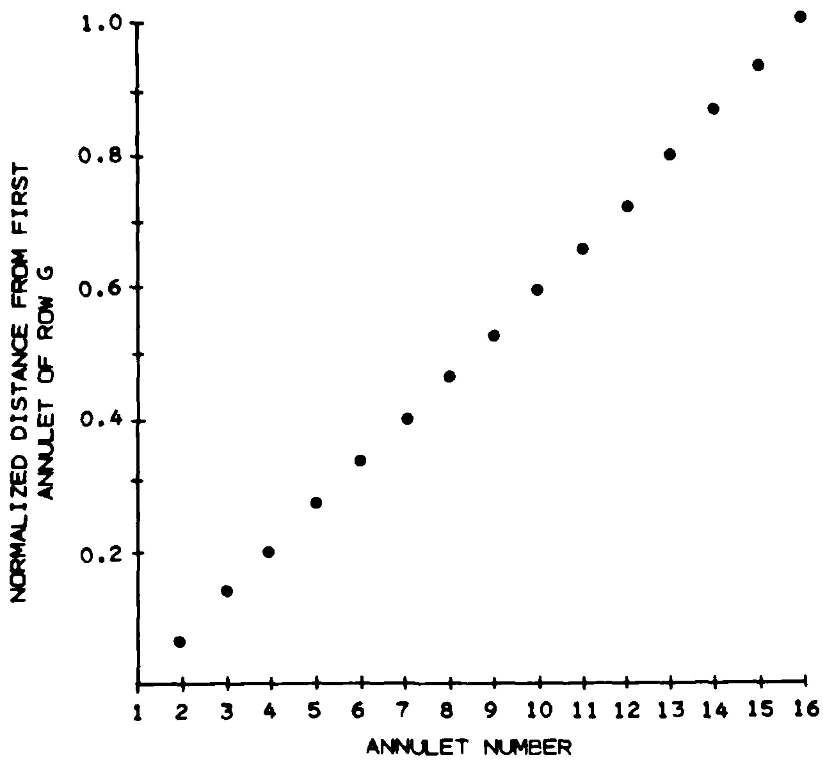


Figure 103. Geometric linearity of the TV camera.

The signal-to-noise ratio (SNR) for the video signal in decibels (dB) is defined as follows:

$$SNR = 20 \log (E_v/E_m),$$

where E_v is the peak-to-peak amplitude of the picture signal (ie, white level and blanking level) and E_m is the RMS random-noise voltage.

5.7.1 TV Camera/Lens System

Original Testing

The SNR for the CGM TV camera was measured as described above. On the video reset beam a 30 millivolt RMS noise level was measured on a 1.0 volt video signal with 0.3 volt synchronous tips. These measured values correspond to an SNR of 32.7 dB. This measured SNR compared favorably with the camera specification of a 30 dB SNR.

Laboratory Retesting

SNR measurements were obtained for the CGM and Cohu cameras and lens systems. Additional measurements were taken with a 4 MHz low pass filter between the camera output and the oscilliscope to enable a direct comparison with the video disc recorder (4 MHz bandwidth). Listed below are the SNR data obtained for the various conditions tested.

	SNR (dB)	
	Camera Only	Camera + Filter
CGM camera	31.9	38.2
Cohu camera	34.5	40.6

The SNR value obtained for the CGM camera during the retesting period (31.9 dB) was similar to the value obtained during the original testing (32.7 dB). The SNR values for the Cohu camera were slightly better than the CGM camera but lower than its camera's specification of 45 dB. An increase in the SNR of approximately 6 dB was obtained for both cameras when the 4 MHz low pass filter was added. This increase in SNR resulted from the reduction of high frequency noise above the 4 MHz region.

5.7.2 Frame Freeze (Video Disc Recorder)

Original Testing

The SNR for the video disc recorder was measured by playing back the white video image recorded from the CGM TV camera. An 11 millivolt RMS noise level was measured on a 0.6 volt video signal with 0.3 volt synchronous tips. These measured values correspond to an SNR of 38.3 dB. A comparison of SNRs for the TV camera/lens system and video disc recorder showed a marked increase for the video disc recorder. This result was not expected, considering that the video disc recorder represents an additional source of noise.

The following conditions may account for this anomalous result. All of the video information (signal) was essentially concentrated at lower frequencies (well below 4 MHz). The TV camera signal bandwidth was on the order of 10 MHz, in contrast to the approximate 4 MHz bandwidth of the video disc recorder signal. This bandwidth disparity would result in a noise power measurement for the camera approximately 8 dB higher than that of the video disc recorder for the same signal power spectral measurement. Thus, when the video recorder and TV camera were compared for the same bandwidth (eg, 4 MHz) -- which is essentially a meaningful comparison -- the TV camera SNR would be 8 dB higher than measured, or 40.7 dB, while the video disc recorder SNR would be as measured, or 38.3 dB.

Retesting of the TV camera/lens system and video disc recorder in conjunction with a 4 MHz filter (similar to that used in the RMDS video terminals) was desired to obtain a comparison of both systems' SNR performance for a common bandwidth. It should be noted that more normal measurements (ie, camera SNR larger than video disc recorder) were obtained during other testing of the RMDS terminals (see sections 5.7.3 and 5.7.4)

Laboratory Retesting

SNR measurements were obtained for the video disc recorder for images supplied by the CGM and Cohu cameras. A 37.6 dB SNR value was obtained for the CGM supplied image, which is close to the original testing value of 38.3 dB. The SNR value obtained for the Cohu supplied image was lower, at 34.0 dB.

Listed below are the SNRs for the video disc recorder and TV cameras under a common bandwidth (4 MHz).

	SNR (dB)	
Camera	TV Camera and Filter	Video Disc Recorder
CGM	38.2	37.6
Cohu	40.6	34.0

A comparison of SNR performance for the TV cameras and video disc recorder under common bandwidth (4 MHz) indicates better performance for the TV cameras, as expected.

5.7.3 **Analog Video Transmission**

Original Testing

Testing was conducted to determine SNRs of analog video transmission using back-to-back, local telephone line, and long distance telephone line communication links. Additional tests were performed to determine the effect of the video disc recorder when used as an image source. Table 33 lists the SNR data obtained for the various test conditions.

Communication Link	SNR (dB) Camera Image	Video Disc Recorder Image
Back-to-Back	26.0	20.0
Local Telephone	30.9	29.8
Long Distance Telephone (Boston)	28.5	26.0
Long Distance Telephone (Seattle)	30.1	28.5
Long Distance Telephone (Chicago)	28.2	28.2
Long Distance Telephone (Boston)	29.9	28.3
Long Distance Telephone (Average)	29.2	27.8

Table 33. Original testing signal-to-noise ratio data for analog video transmission.

The SNRs ranged from 26.0 to 30.9 dB for the camera image and 20.0 to 29.8 dB for the disc recorder image. A comparison of camera image versus video disc recorder image showed a marked decrease in SNR for the latter. This would be expected since the use of the video disc recorder represented an additional source of signal distortion. In view of the small sample size for each communication link and fairly large dispersion of random variables, limited emphasis should be attached to the listed SNR values.

Laboratory Retesting

Testing was conducted to determine SNRs of analog video transmissions using back-to-back, local telephone line, and long distance telephone line communication links. Additional tests were performed to determine the effect of the video disc recorder when used as an image source for transmission. Table 34 lists the SNR data obtained for the various test conditions.

	SNR (dB)			
	Camera		Video Disc Recorder	
Communication Link	CGM	Cohu	CGM	Cohu
Back-to-Back	38.8	38.2	38.3	37.7
Local Telephone	38.7	38.1	37.3	37.6
Long Distance Telephone (Seattle)	35.6	37.1	35.2	35.9

Table 34. Laboratory retesting signal-to-noise ratio data for analog video transmission.

The SNRs for the conditions tested were similar, ranging from 35.2 to 38.8 dB. Long distance telephone provided the lowest SNR of all the communication links, with SNR values ranging from 35.2 to 37.1 dB. A slight decrease in SNR was observed for the video disc recorder images. This was expected since the use of the video disc recorder represented an additional source of signal distortion. A marked increase in SNR values was seen when the values obtained during the retesting period were compared to those obtained during the original testing period. A possible cause for the observed increase in SNR values may be related to the time of day in which the test took place. (See section 3.4, Laboratory Retesting.)

5.7.4 Digital Video Transmission

Original Testing

Testing was conducted to determine SNRs of digital video transmission using back-to-back, local telephone line, and long distance telephone line communication links. Additional tests were performed to determine the effect of the video disc recorder when used as an image source. Table 35 lists the SNR data obtained for the various test conditions.

	SNR (dB)	
Communication Link	Camera Image	Video Disc Recorder Image
Back-to-Back	26.0	21.4
Local Telephone	26.0	23.3
Long Distance Telephone (Boston)	30.1	26.0
Long Distance Telephone (Seattle)	28.2	28.2
Long Distance Telephone (Chicago)	33.5	23.6
Long Distance Telephone (Average)	30.6	25.9

Table 35. Original testing signal-to-noise ratio data for analog video transmission.

The SNR ranged from 26.0 to 33.5 dB for the camera image and 21.4 to 28.2 dB for the video disc recorded image. A comparison of camera image versus video disc recorder image showed a marked decrease in SNR for the video disc recorder image, as seen in the analog video transmission (section 5.7.3).

Laboratory Retesting

Testing was conducted to determine SNRs of digital video transmission using back-to-back, local telephone line, and long distance telephone line communication links. Additional tests were performed to determine the effect of the video disc recorder when used as an image source. Table 36 lists the SNR data obtained for the various test conditions.

Communication Link	SNR (dB) Camera CGM	Camera Cohu	Video Disc Recorder CGM	Video Disc Recorder Cohu
Back-to-Back	40.0	38.2	38.9	37.4
Local Telephone	39.2	38.7	38.8	38.2
Long Distance Telephone (Seattle)	37.7	38.2	36.8	36.8

Table 36. Laboratory retesting signal-to-noise ratio data for digital video transmission.

The SNRs for the conditions tested were similar, ranging from 36.9 to 40.0 dB. An increase in the SNR was observed for digital video transmissions when compared to analog video transmissions of the same mode. As in analog video transmissions, long distance telephone line SNRs were the lowest of all the communication links. A marked increase in SNR data was also seen of values obtained during the retesting period compared to those obtained during the original testing period.

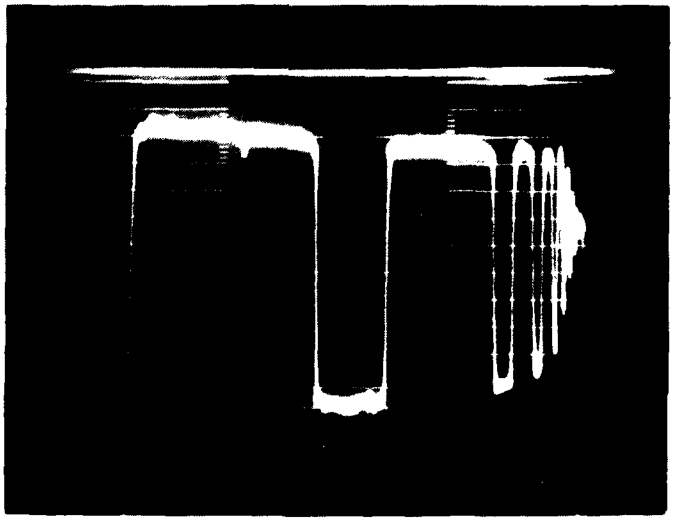
5.8 EQUALIZATION

Testing was conducted to determine whether the video system elements exhibited any significant overshoot, smear, or streaking for sharp black-to-white edge structures. The RMDS terminals were set up for video image utilization. The Resolution Measurement Test Pattern, figure 58, was used to provide the black-to-white edge structures. The TV camera aperture, focus, and field of view were adjusted for optimum image presentation of the 7-1/2"x10" area of the test pattern. The BLACK LEVEL and VIDEO LEVEL controls of the image compression unit were set as required by the test. An oscilloscope was used to display a single horizontal TV line from the composite video signal of the image being viewed. The horizontal line intersected the 0.05 lp/mm horizontal bar directly beneath the two-sided bar pattern in the center of the test pattern. The horizontal line display on the oscilloscope was expanded, then the oscilloscope time delay was adjusted to display the video signal representing the black-to-white transition on the left side of this bar. Photographs were taken of the oscilloscope presentation, and later these were analyzed to determine whether the black-to-white transition resulted in any overshoot or smear.

5.8.1 TV Camera/Lens System

Figure 104 shows photographs taken during the testing of the TV camera and lens system. The top photograph shows the signal obtained directly from the TV camera, while the bottom photograph shows the same signal with a low pass filter between the camera and the oscilloscope. The low pass filter decreased the amount of noise on the signal without distorting the signal's shape. As can be seen in the lower photograph (figure 104), little to no overshoot occurs. The values for rise time and fall time are 0.8 and 0.3 microsecond, respectively. This indicated that under the worst condition (black-to-white, rise time) approximately 1.5 % of the active sweep time will possess smear. This appeared to be within tolerance.

(a) Without low pass filter between camera and oscilloscope



(b) With low pass filter between camera and oscilloscope

Figure 104. Equalization photographs for TV camera/lens system.

5.8.2 Frame Freeze (Video Disc Recorder)

The video recorder was tested for equalization by playing back a recorded image of the Resolution Measurement Test Pattern. No appreciable overshoot was observed for black-to-white transition, but a low amplitude 2.5 MHz noise was present at the black and white signal levels. The rise and fall times for black-to-white transition were equal with a value of 0.36 microsecond. This indicated that 0.7% of the active sweep time would possess smear, and the effect of smear would be minimal.

5.8.3 Analog Video Transmission

Equalization tests were done in the analog video transmission mode using back-to-back, local telephone line, and long distance telephone line communication links. The effect of the video disc recorder was also tested using local telephone and long distance telephone line communication links. Figures 105 and 106 show photographs of the three different communication links without the video disc recorder in use. The photographs taken when the video disc recorder was used were similar in all respects. The amount of high frequency noise seen at the black and white signal level was relatively constant between the back-to-back and local telephone line communication links but increased noticeably on the black signal level for the long distance telephone line link. Table 37 shows the data obtained from the oscilloscope photographs. The value of overshoot was calculated by dividing one half the peak-to-peak value of the first ring cycle by the amplitude of the signal.

Test Condition	Rise Time (microseconds)	Fall Time (microseconds)	Overshoot (percent)
Back-to-Back	0.24	0.30	11
Local Telephone	0.12	0.24	8
Local Telephone/Disc	0.22	0.26	7
Long Distance Telephone	0.28	0.26	9
Long Distance Telephone/Disc	0.18	0.22	9

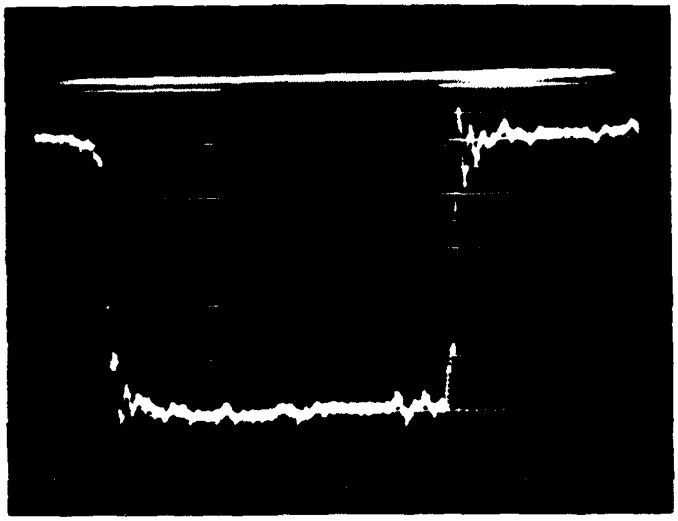
Table 37. Equalization measurements for analog video transmissions.

The rise and fall time for all conditions tested were very similar in magnitude, and were typical of a 4 MHz bandwidth system.

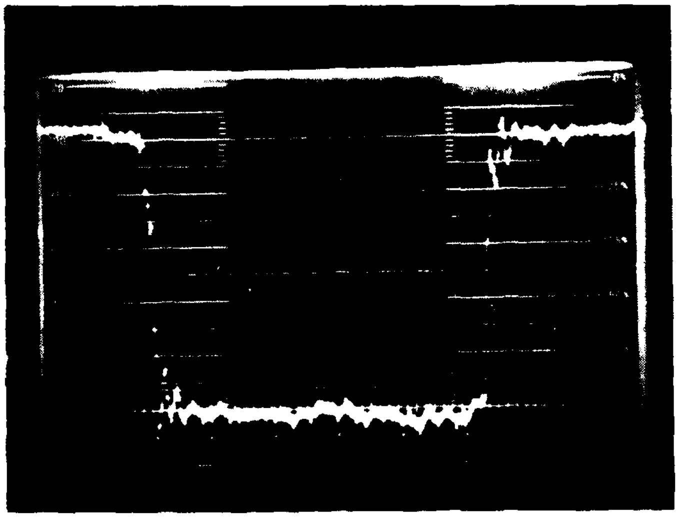
A 4 MHz ringing was present during each transition, which made measurement of overshoot difficult. The measurements of overshoot for all conditions tested were of similar magnitude and ranged from 7 to 11%, with the transition oscillations leveling out after approximately 0.8 microsecond. It should be noted that ringing is characteristic of an underdamped tuned circuit, and some small underdamping (resulting in overshoot) can be useful in that it tends to accent edges.

5.8.4 Digital Video Transmission

Equalization tests were conducted in the digital video transmission mode using back-to-back, local telephone line, and long distance telephone line communication links. The effect of the video disc recorder was also tested for the above communication links. Figures 107 and 108 show photographs of the three different communication links without the video recorder in use. Noise was present at both the black

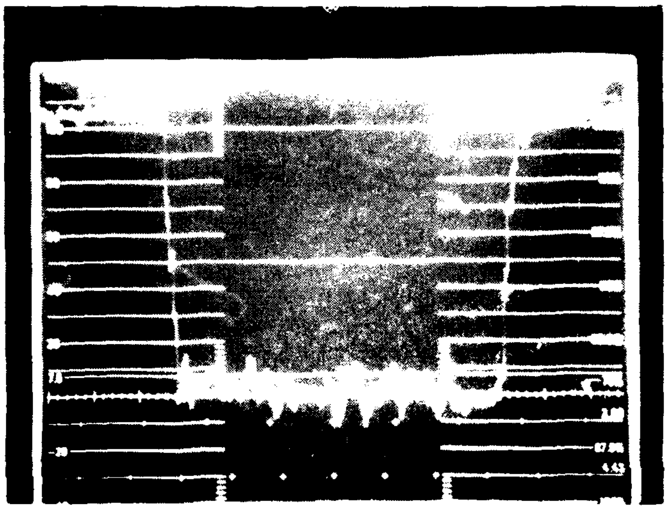


(a) Back-to-back communication link



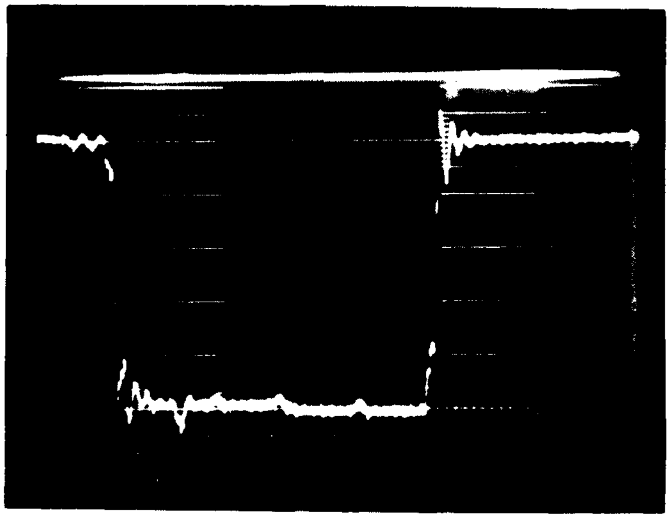
(b) Local telephone line communication link

Figure 105. Equalization photographs for analog video transmission.

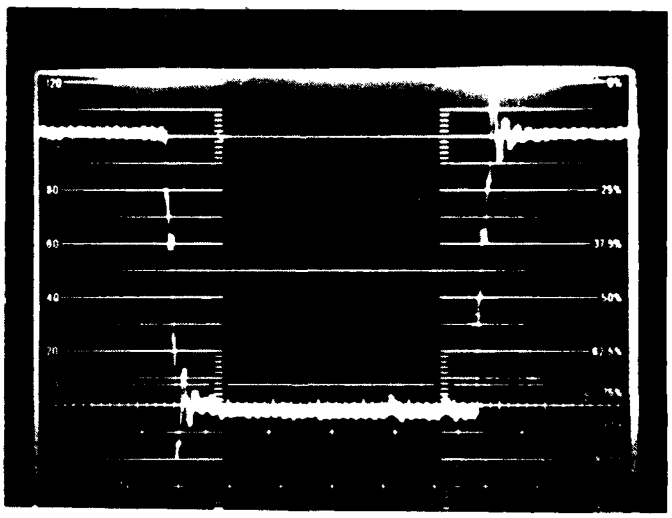


Long distance telephone line communication link

Figure 106. Equalization photograph for analog video transmission.

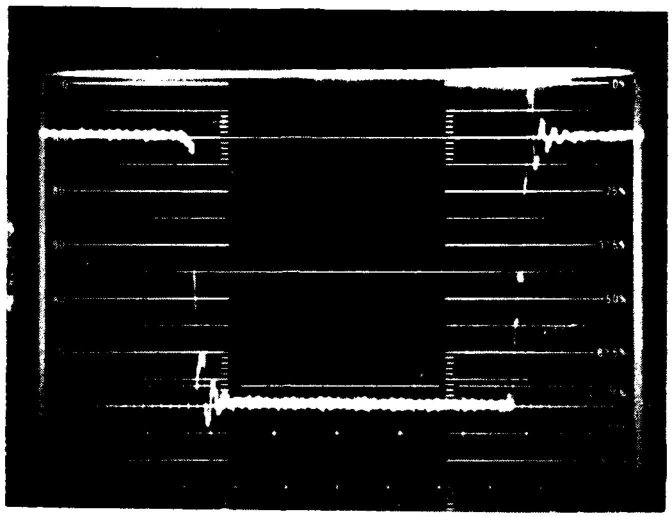


(a) Back-to-back communication link



(b) Local telephone line communication link

Figure 107. Equalization photographs for digital video transmission.



Long distance telephone line communication link

Figure 108. Equalization photograph for digital video transmission.

and white signal levels, but tended to be more structured with respect to amplitude than that seen for the analog mode (figures 105 and 106). Photographs taken while the video disc recorder was used were similar in all respects. Table 38 shows the data obtained from the oscilloscope photographs.

Test Condition	Rise Time (microseconds)	Fall Time (microseconds)	Overshoot (percent)
Back-to-Back	0.22	0.24	10
Back-to-Back/Disc	0.30	0.36	7
Local Telephone	0.32	0.24	11
Local Telephone/Disc	0.32	0.04*	9
Long Distance Telephone	0.24	0.04*	13
Long Distance Telephone/Disc	0.20	0.36	13

*Excess ringing at fall time measurement positions

Table 38. Equalization measurements for digital video transmissions.

The rise and fall times for the conditions tested were very similar, with the exception of fall time for local and long distance telephone line communication links. As can be seen in figures 107 and 108, the 4 MHz ringing which accompanied the white-to-black transitions interfered with the fall time measurements and contributed to the distorted values of 0.04 microsecond. The rise and fall time measurements for the conditions tested were similar in magnitude and typical of a 4 MHz bandwidth system.

As in the analog video transmission tests, because ringing distorted the measurements of overshoot, the same procedure was used to estimate overshoot. Measurements of overshoot for all conditions tested were of similar magnitude and ranged from 7 to 13%.

5.9 VIDEO RECORDER TIME BASE STABILITY

Testing was conducted to measure the time base stability of the horizontal line rate for the video recorder (frame freeze) system. The RMDS terminal was set up for video image use. The TV camera was adjusted for an optimum video presentation of the lighted viewbox without a test pattern. The image was recorded on the video recorder and played back for measurement purposes. An oscilloscope was used to view a single horizontal TV line of the composite video, triggered on the horizontal sync pulse for the image being viewed. The time base for the oscilloscope was set to include the next blanking and sync pulse at the right of the oscilloscope presentation. An oscilloscope was used to measure stability visually.

The separation between successive leading and trailing sync tip edges was measured to be approximately 62.5 microseconds. A 1.6% (1.0 microsecond peak-to-peak) jitter was observed, and over a period of 5 minutes the signal drifted 3.2% (2.0 microseconds peak-to-peak). Although the amount of jitter and drift are small, the effects would manifest themselves as smear and decreased resolution in the horizontal direction. The cause of the time base instability was the slight change in disc rotation speed.

5.10 VIDEO TRANSMISSION TIME

Tests were conducted to measure the time required to transmit an image between the RMDS terminals. The RMDS terminals were set up for video image transfer. The transmission modes tested included analog, 2400 bps, 4800 bps, and 9600 bps, fine and coarse resolution. Transmission time was recorded as the amount of time from depressing of the TRANSMIT START button on the transmitter terminal until the vertical white line in the TV monitor display returned to its static center position at the completion of the video transmission. Table 39 shows the values obtained for transmission time under the above conditions.

Transmission Mode	Video Transmission Time (s)	
	Coarse: 256 x 256	Fine: 525 x 256
Analog	34	78
2400 bps	179	366
4800 bps	94	196
9600 bps	51	111

Table 39. Transmission time versus resolution and mode selection.

5.11 GRAY SCALE RESPONSE MEASUREMENTS

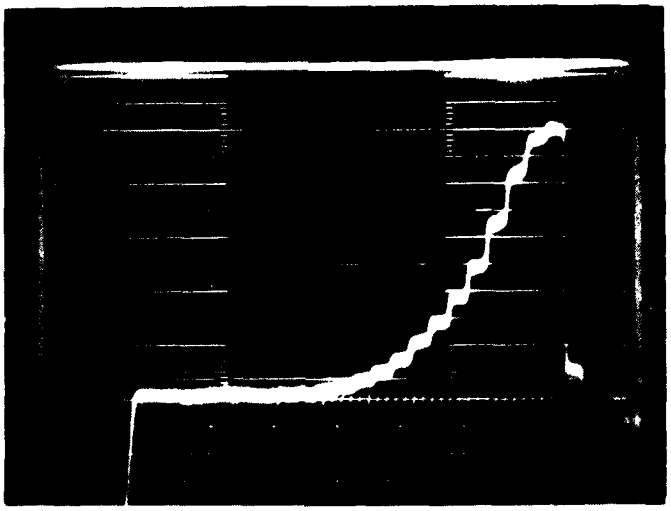
Testing was conducted to determine the response of selected video system elements to the full dynamic range of order level inputs. The RMDS transmitting/receiving terminals were set up for video use. A calibrated step tablet, varying in optical density from 0.04 to 3.01 units of diffused density, was placed on the illuminated view box so that the long axis of the step tablet was horizontal when viewed on the TV monitor. The TV camera was adjusted for optimal presentation of the step tablet. An oscilloscope was used to view one horizontal TV line through the length of the step tablet, and photographs were taken for analysis. Figure 109 shows representative photographs of the oscilloscope display for the TV camera/lens system and frame freeze (video disc recorder).

The initial signal observed on the oscilloscope was accompanied by an excess of high frequency noise. To reduce this noise, the low pass filter (IRE, -22 dB at 4.43 MHz) built into the Tektronix 466 Storage oscilloscope was used. This aided in the signal measurements without increased signal distortion.

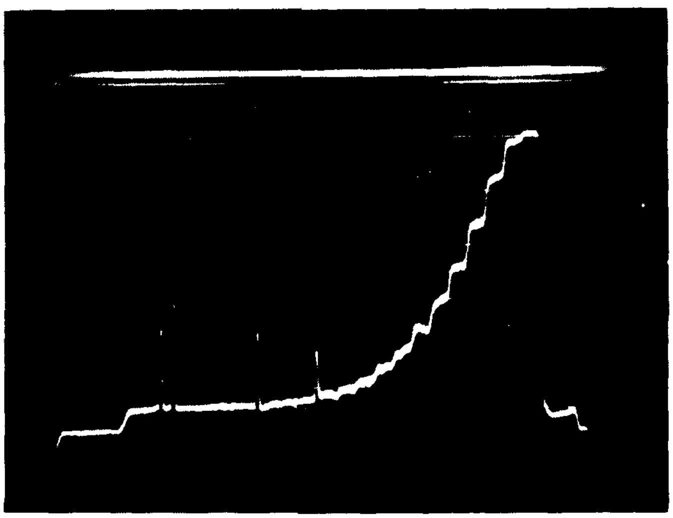
5.11.1 TV Camera/Lens System

Original Testing

The CGM camera was tested for gray scale response as described in section 5.11. The data obtained in this test are listed on table 40 and plotted in figure 110. The curve for the CGM camera shows a reduced and nonlinear response for the low optical densities (to about 0.2 OD) and the ability to image the range of optical densities up to 1.8. Thus, a dynamic range for the camera's response to light input of about



(a) TV camera/lens system



(b) Frame freeze (video recorder)

Figure 103. Gray scale photographs for TV camera and frame freeze system, using IRE filter.

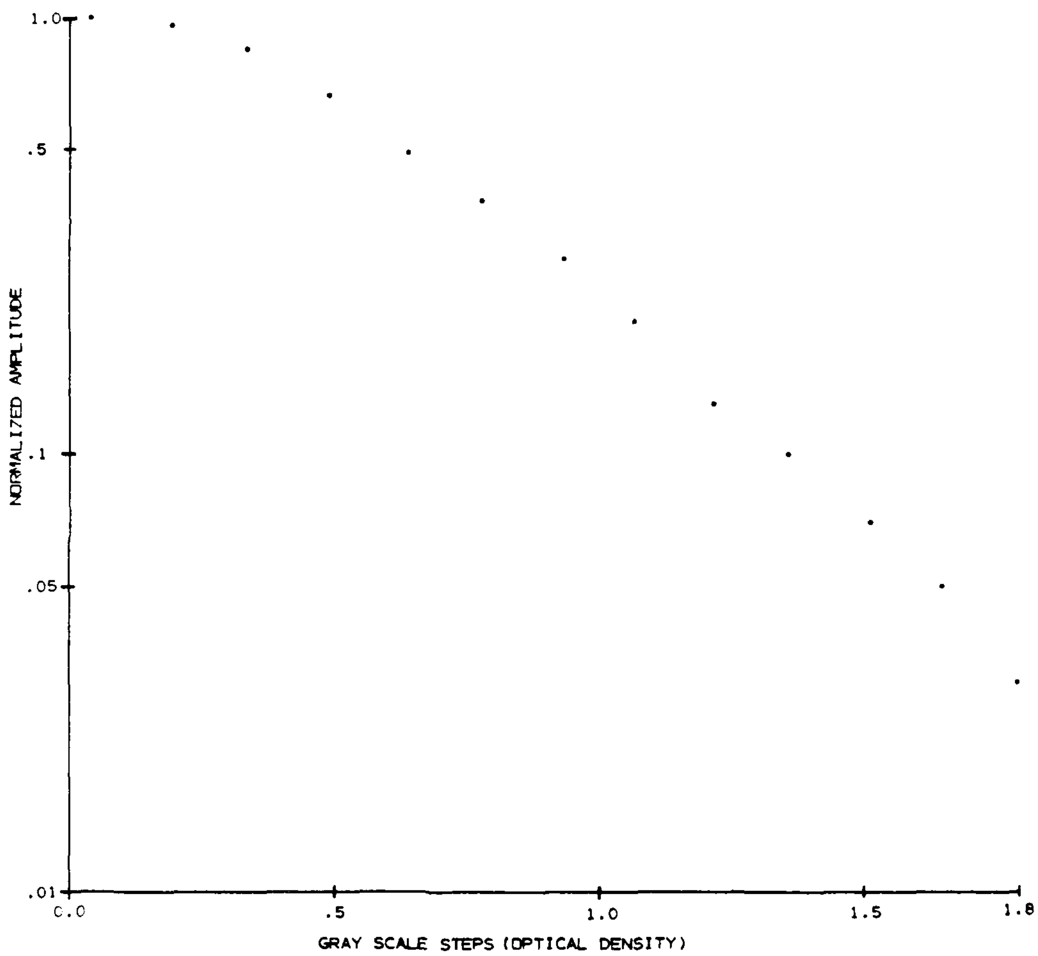


Figure 110. Gray scale response for TV camera/lens system.

Gray Scale Steps (Optical Density)	Normalized Amplitude
0.04	1.00
0.19	0.96
0.34	0.85
0.49	0.66
0.64	0.49
0.78	0.38
0.93	0.28
1.07	0.20
1.22	0.13
1.36	0.10
1.51	0.07
1.65	0.05
1.80	0.03

Table 40. Gray scale response data for TV camera/lens system (CGM).

Gray Scale Steps (Optical Density)	Normalized Amplitude
0.04	1.00
0.19	0.96
0.34	0.89
0.49	0.63
0.64	0.50
0.78	0.39
0.93	0.30
1.07	0.22
1.22	0.17
1.36	0.11
1.51	0.07
1.65	0.05
1.80	0.02

Table 41. Gray scale response data for TV camera/lens system (Cohu).

60:1 resulted from the ability to detect a minimum transmittance on the order of 1.6% of incident light before being masked by noise, compared to 100% transmittance representing saturation by the input light.

The gray scale response for the CGM camera was satisfactory. The CGM camera had 13 distinct shades of gray as determined by oscilloscope signal level display and visual observation of the gray scale step pattern on the TV monitor. The CGM camera met RMDS specifications, which call for 10 distinct shades of gray at normal illumination levels.

Laboratory Retesting

The Cohu camera was tested for gray scale response. The data obtained in this test is listed in table 41 and plotted in figure 111. A comparison of the curves in figures 110 and 111 indicated similar gray scale response for the CGM and Cohu cameras. The dynamic range for the Cohu camera's response to light input was also on the order of 60:1. The gray scale response for the Cohu camera was satisfactory. The Cohu camera had 13 distinct shades of gray as determined by oscilloscope signal level display and visual observation of the gray scale step pattern on the TV monitor.

5.11.2 Frame Freeze (Video Disc Recorder)

Original Testing

Testing was conducted to determine the gray scale response of the video disc recorder. A CGM TV camera image of the test pattern was recorded and played back for measurement. The data obtained in this test are listed in table 42 and plotted in figure 112. The response curve for the video disc recorder was identical to the one obtained for the CGM camera. This indicated that the video disc recorder was able to reproduce gray scale quality similar to that of the CGM camera.

Laboratory Retesting

Testing was conducted to determine the gray scale response of the video disc recorder for the Cohu camera image. The data obtained in this test are listed in table 43 and plotted in figure 113. The response curve for the video disc recorder was identical to that of the Cohu camera. This indicated that the video disc recorder was able to reproduce gray scale quality similar to that of the Cohu camera.

5.11.3 Analog Video Transmission

Original Testing

Testing was conducted to determine the gray scale response of analog video transmission using back-to-back and local telephone line communication links. The CGM camera and video disc recorder were used as image sources at the transmitting terminal.

A 1 MHz noise was observed on the gray scale signal which was not present during the tests of the CGM camera or video disc recorder. A similar 1 MHz noise was observed in the noise level testing for ECG and stethoscope (sections 3.4 and 4.5, respectively), and may originate from the same unknown source. The noise had its

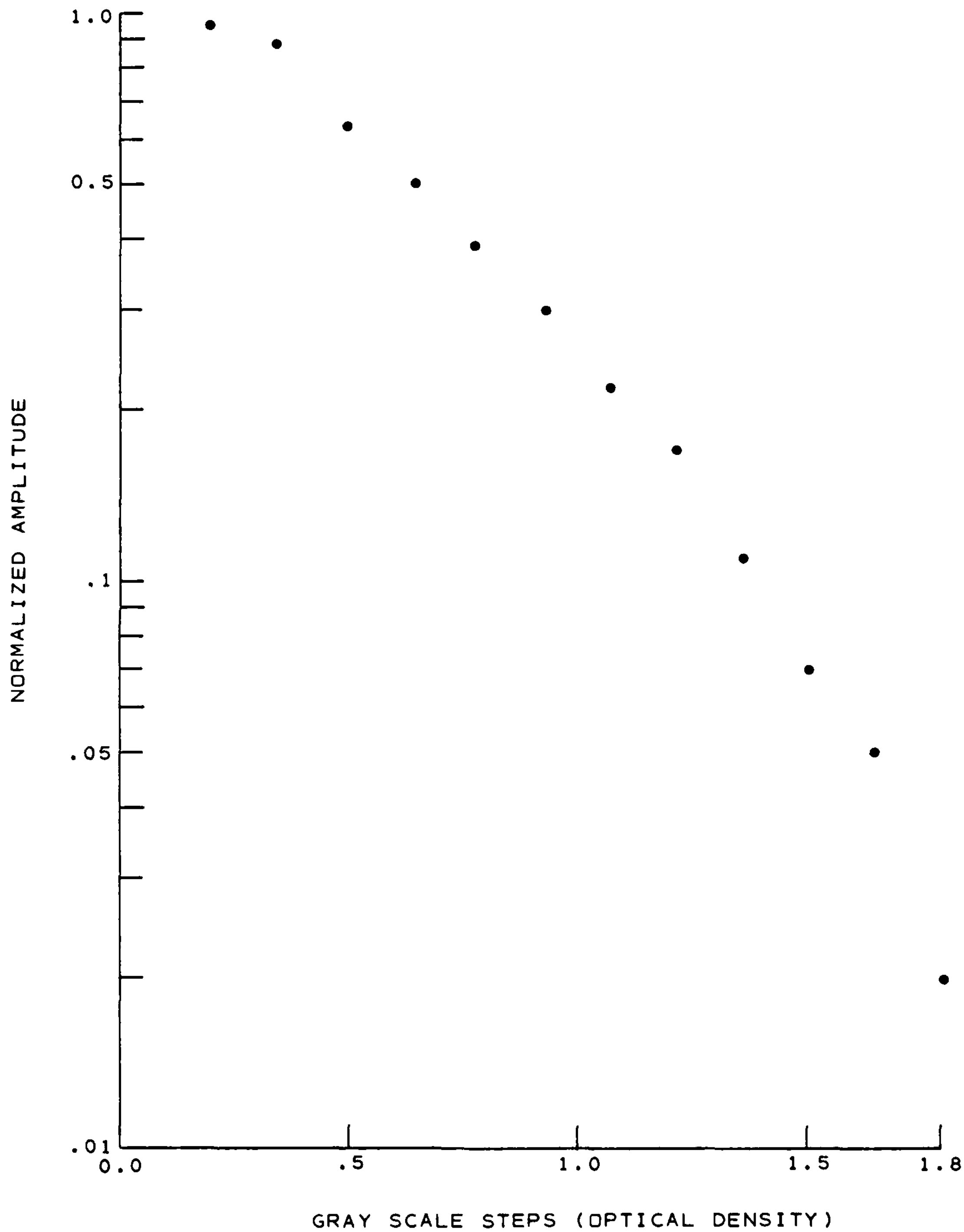


Figure 111. Gray scale response for Cohu camera.

Gray Scale Steps (Optical Density)	Normalized Amplitude
0.04	1.00
0.19	0.98
0.34	0.85
0.49	0.68
0.64	0.52
0.78	0.39
0.93	0.30
1.07	0.21
1.22	0.14
1.36	0.08
1.51	0.06
1.65	0.05
1.80	0.04

Table 42. Gray scale response data for frame freeze (CGM).

Gray Scale Steps (Optical Density)	Normalized Amplitude
0.04	1.00
0.19	0.96
0.34	0.78
0.49	0.63
0.64	0.50
0.78	0.38
0.93	0.30
1.07	0.22
1.22	0.16
1.36	0.11
1.51	0.07
1.65	0.04
1.80	0.02

Table 43. Gray scale response data for frame freeze (Cohu).

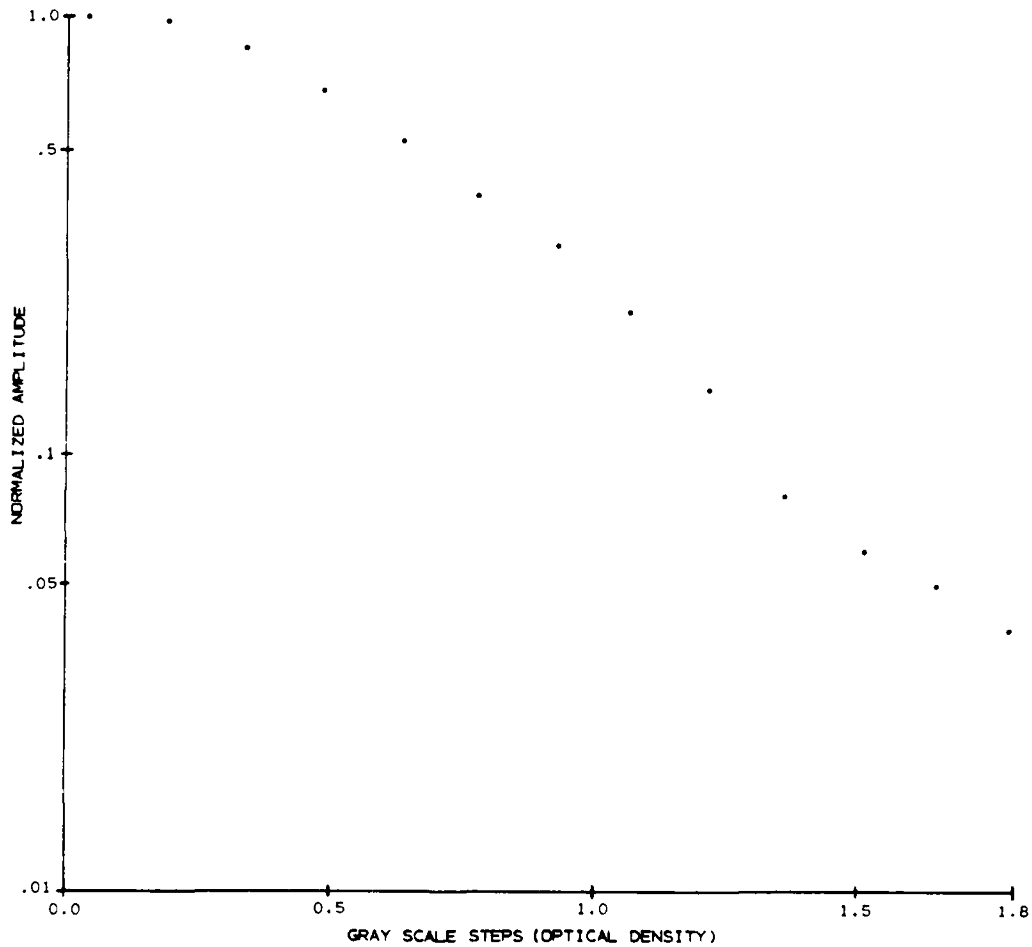


Figure 112. Gray scale response for frame freeze (video recorder).

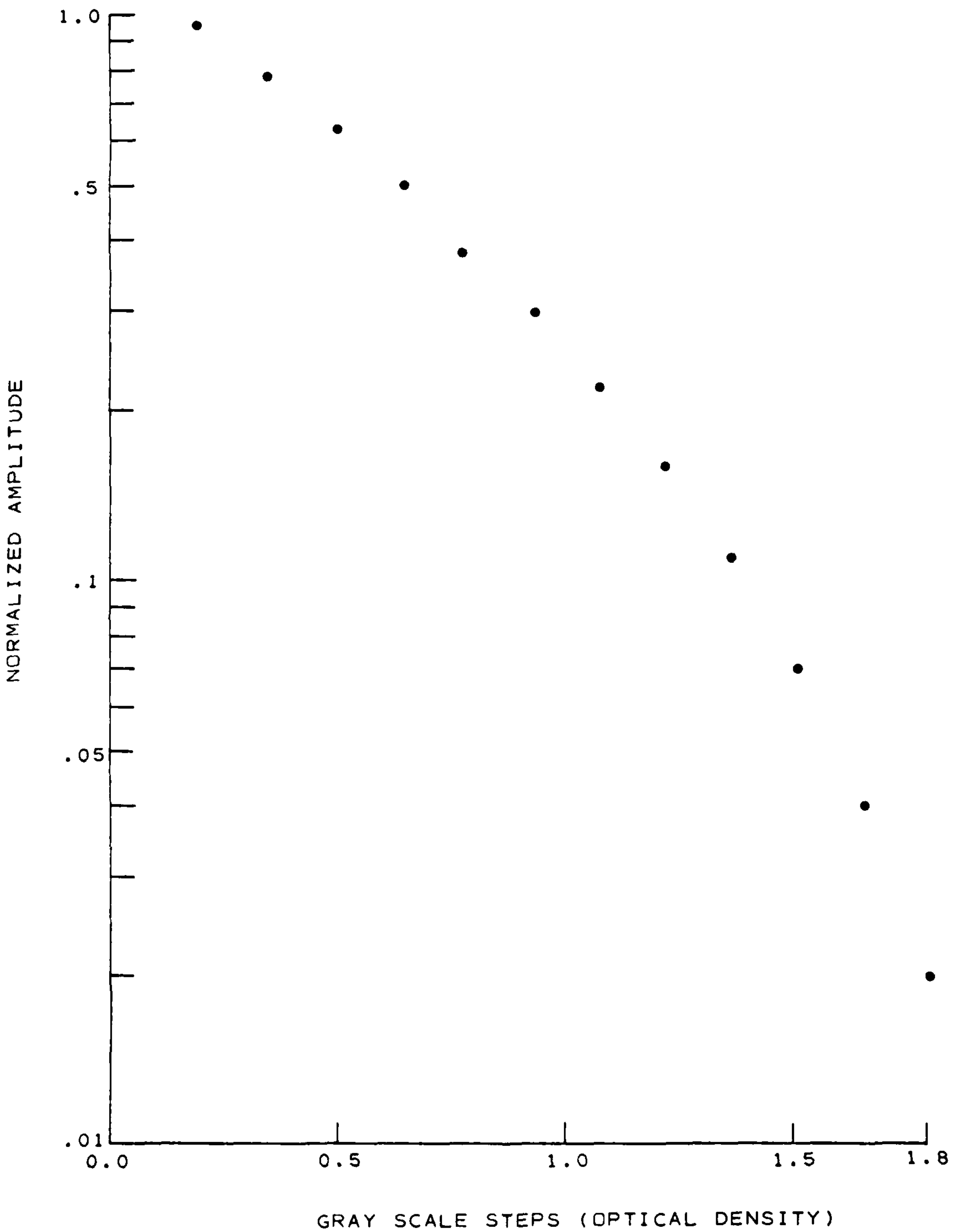


Figure 113. Gray scale response for frame freeze, Cohu image.

greatest effect with the back-to-back communication link, and amplitude measurements could not be made beyond the 0.64 optical density level.

The data obtained in these tests are listed in tables 44 and 45. The response curves for the camera image in back-to-back and local telephone line configurations are plotted in figure 114. The measurements obtained for the camera image and video disc recorder image in the local telephone line configuration are essentially the same (see table 44). This further demonstrates the ability of the video disc recorder to reproduce gray scale response similar to the camera image.

The response curves shown in figure 114 (back-to-back and local telephone line) are similar in shape to those of the nontransmitted TV camera and video disc (figures 110 and 112). The increase in noise (1 MHz) on the received signal of the back-to-back and local telephone configurations makes it difficult to determine the decrease in response due to image transmission. The number of distinguishable gray levels and the dynamic range are a function of both the slope of the response curve and the SNR. Therefore, a decrease in gray scale response and dynamic range would be expected as noise levels increased during transmission.

It should be noted that from the oscilloscope presentation that only 5 gray levels could be measured for back-to-back and 10 gray levels for the local telephone line, whereas 8 and 10 gray levels, respectively, could be visually distinguished from the TV monitor.

Laboratory Retesting

Testing was conducted to determine the gray scale response of analog video transmission using back-to-back, local, and long distance telephone line communication links. The Cohu camera and video disc recorder were used as image sources at the transmitting terminal. The amount of noise observed on the oscilloscope display tended to increase with the transition from back-to-back to local to long distance telephone line communication links. This increase in noise can be seen in figure 115, which shows photographs of the oscilloscope display for the back-to-back and long distance telephone line communication links.

The data obtained in the analog transmission mode gray scale testing are listed in table 46. The response curves for the camera images of the various communication links are plotted on figure 116. The measurements obtained for the various test conditions were essentially the same, as seen in table 46 and figure 116. The video disc recorder reproduced a gray scale response similar to the TV camera image. Listed below are the number of distinguishable gray levels observed on the TV monitor for the conditions tested.

	Number of Gray Levels	
Communication Link	Camera	Video Disc Recorder
Back-to-Back	11	11
Local Telephone	12	11
Long Distance Telephone	10	9

Gray Scale Steps (Optical Density)	Normalized Amplitude
0.04	1.00
0.19	0.92
0.34	0.78
0.49	0.68
0.64	0.58

Table 44. Gray scale response data for analog video transmission, back-to-back (CGM).

Gray Scale Steps (Optical Density)	Normalized Amplitude	
	Camera	Video Recorder
0.04	1.00	1.00
0.19	0.96	0.96
0.34	0.80	0.79
0.49	0.64	0.64
0.64	0.52	0.51
0.78	0.38	0.37
0.93	0.31	0.29
1.07	0.21	0.20
1.22	0.15	0.15
1.36	0.10	0.10

Table 45. Gray scale response data for analog video transmission, local telephone line (CGM).

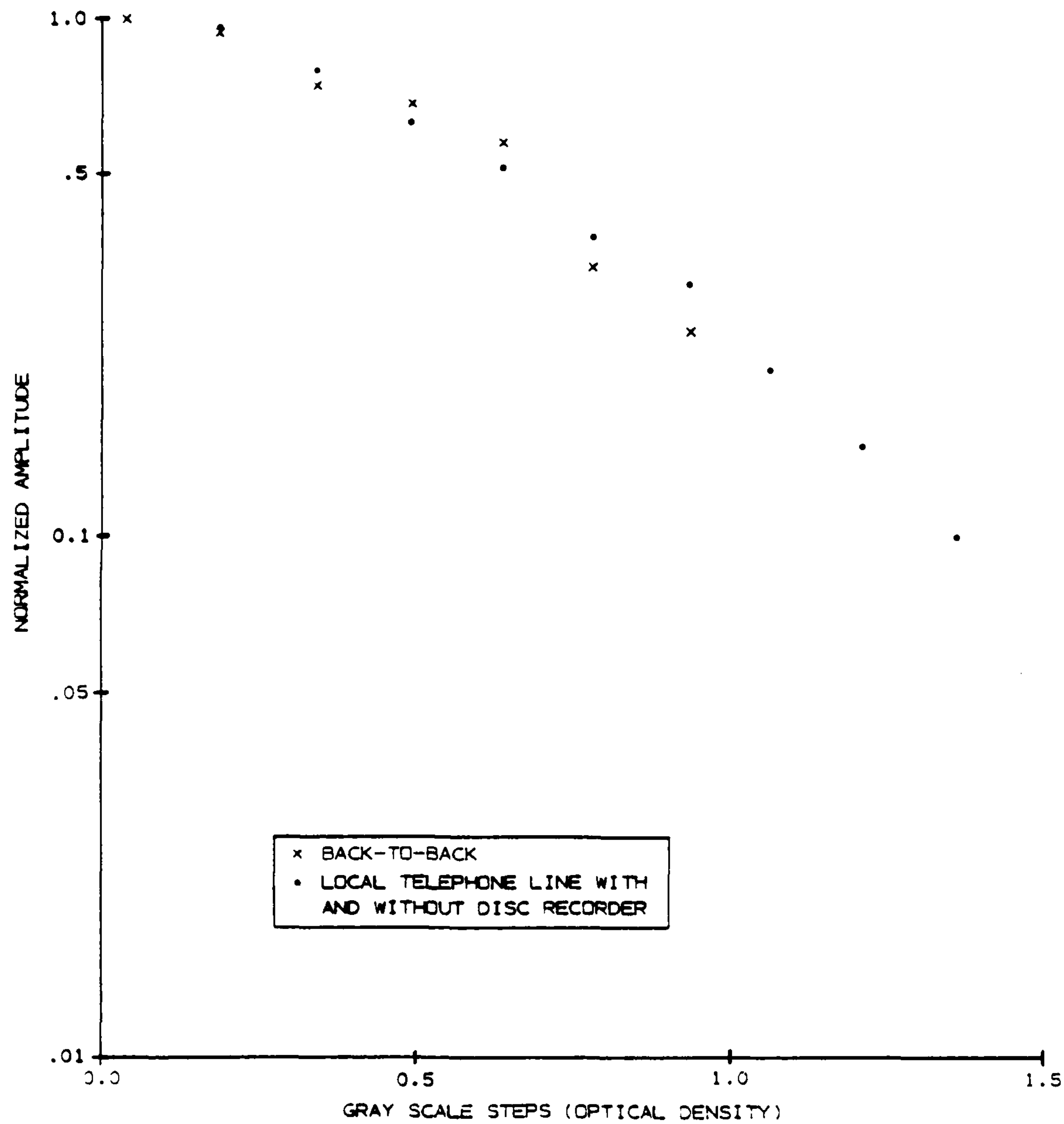
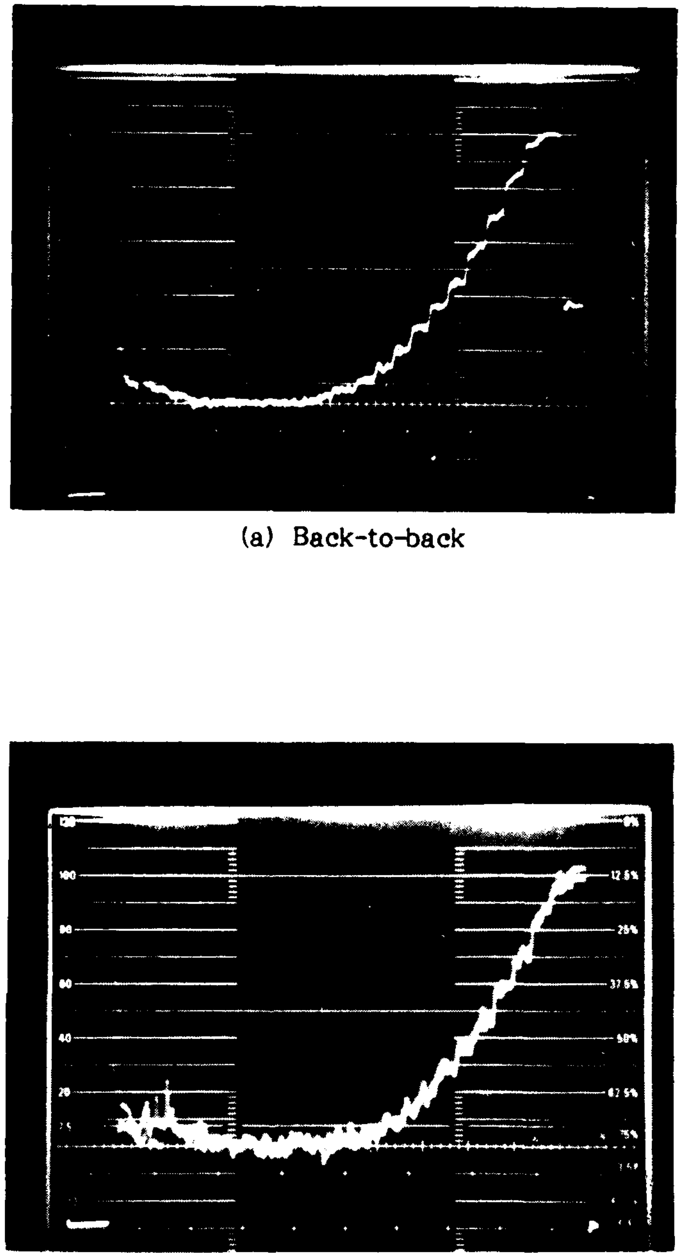


Figure 114. Gray scale response for analog video transmission, camera image.



(a) Back-to-back

(b) Long distance telephone

Figure 115. Gray scale photographs for anal[illegible] Cohu camera.

AD-A114 073 WESTEC SERVICES INC SAN DIEGO CA F/G 6/5
REMOTE MEDICAL DIAGNOSIS SYSTEM (RMDS) ADVANCED DEVELOPMENT MOD--ETC(U)
JAN 82 W T RASMUSSEN, I STEVENS, P D HAYES N66001-78-C-0274

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	Normalized Amplitude					
Gray Scale	Back-to-Back		Local Telephone		Long Distance Telephone	
(Optical Density)	Camera	VDR	Camera	VDR	Camera	VDR
0.04	1.00	1.00	1.00	1.00	1.00	1.00
0.19	0.96	0.96	0.96	0.97	0.96	0.89
0.34	0.85	0.83	0.84	0.83	0.85	0.83
0.49	0.69	0.68	0.70	0.70	0.70	0.70
0.78	0.44	0.43	0.46	0.45	0.46	0.45
0.93	0.36	0.34	0.37	0.36	0.36	0.35
1.07	0.28	0.26	0.28	0.28	0.28	0.25
1.25	0.20	0.18	0.20	0.19	0.18	0.16
1.36	0.13	0.13	0.14	0.13	0.14	0.10
1.51	0.08	0.07	0.10	0.08	0.08	
1.65	0.05	0.04	0.06	0.06		
1.80	0.02		0.05	0.04		

Table 46. Gray scale response data for analog video transmission (Cohu).

VDR - Video Disc Recorder

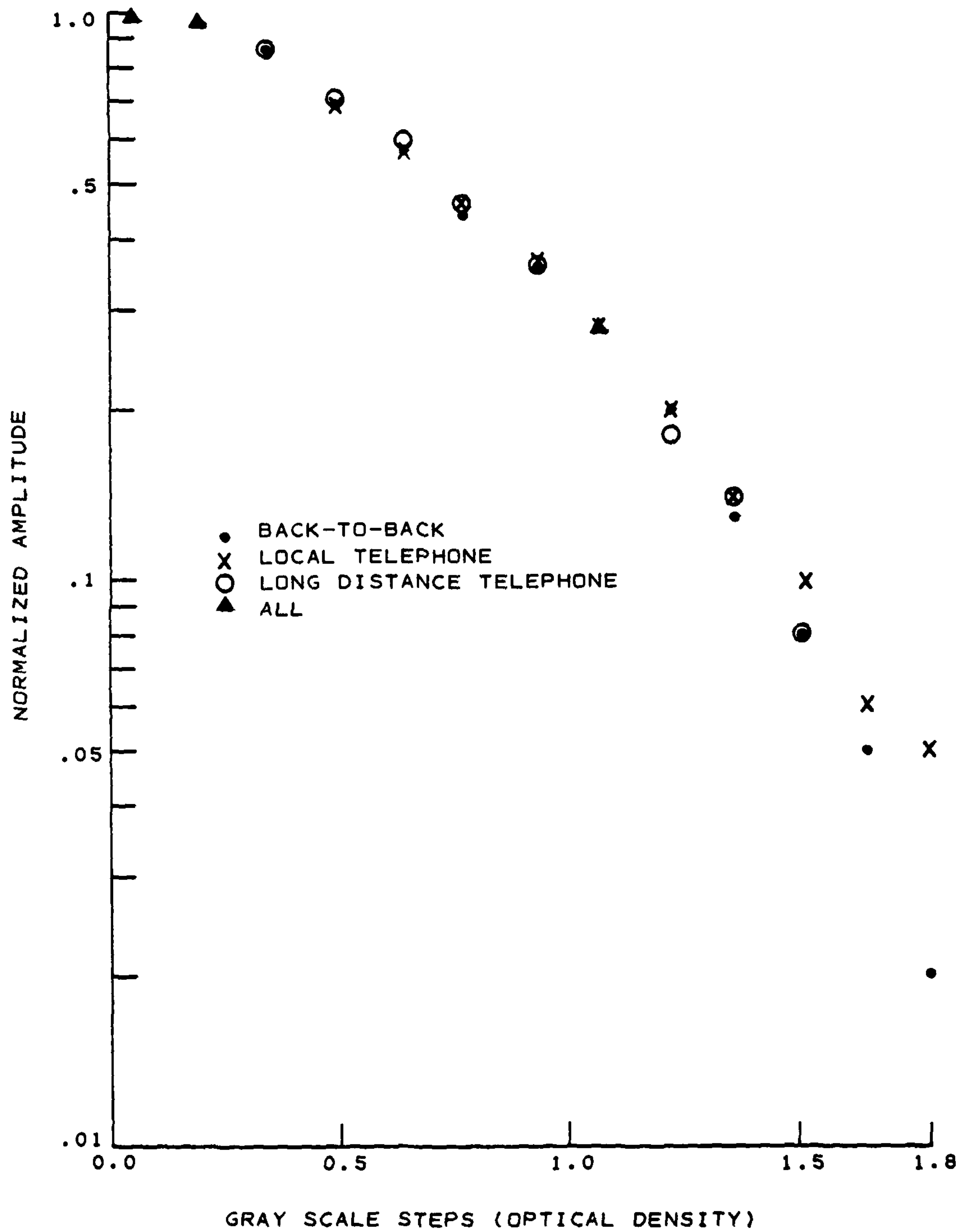


Figure 116. Gray scale response for analog video transmission, Cohu image.

The 1 MHz noise observed during the original gray scale testing was not seen during the retesting period, although random noise was present. The increase in number of distinguishable gray levels observed for the retesting period can be attributed to this decrease in noise. The reduction in noise could be due to 1) reduction in environmental ambient noise levels, 2) improvement in camera performance characteristics, or 3) a combination of these two factors.

5.11.4 Digital Video Transmission

Original Testing

Testing was conducted to determine the gray scale response of digital video transmission by using back-to-back, local telephone line, and long distance telephone line communication links. The CGM camera and the video disc recorder were used as image sources at the transmitting terminal. A 1 MHz noise, similar to that mentioned in the analog gray scale test (section 5.11.3), was observed under all test conditions. As before, the noise had its greatest effect on the back-to-back communication mode, andamplitude measurements of gray scale steps were limited to the lower optical density levels. The data obtained in these tests are plotted in figure 117 and listed in table 47. A noticeable increase in the slope of the gray scale response curve can be seen for the long distance telephone line configuration.

The values obtained for the camera image and the video disc recorder were essentially equal under similar test conditions (see table 47). Again, the video disc recorder reproduced the image faithfully with respect to gray scale response. As in the analog mode, a difference existed between the number of gray levels distinguishable on the oscilloscope and the TV monitor. The number of gray levels obtained for the digital transmission mode were as follows:

	Number of Gray Levels	
Communication Link	Oscilloscope	TV Monitor
Back-to-Back	7	9
Local Telephone	9	10
Long Distance Telephone	9	10

The number of distinguishable gray levels is a function of the response curve and the SNR. The SNR measurements obtained for the above communication links (section 5.7.4) correspond with the number of gray levels, with back-to-back having the lowest SNR.

Laboratory Retesting

Testing was conducted to determine the gray scale response of digital video transmissions using back-to-back, local, and long distance telephone line communication links. The Cohu camera and video disc recorder were used as image sources at the transmitting terminal. The data obtained in this testing are listed in table 48. The response curves for the camera images on the various communication links are plotted in figure 118.

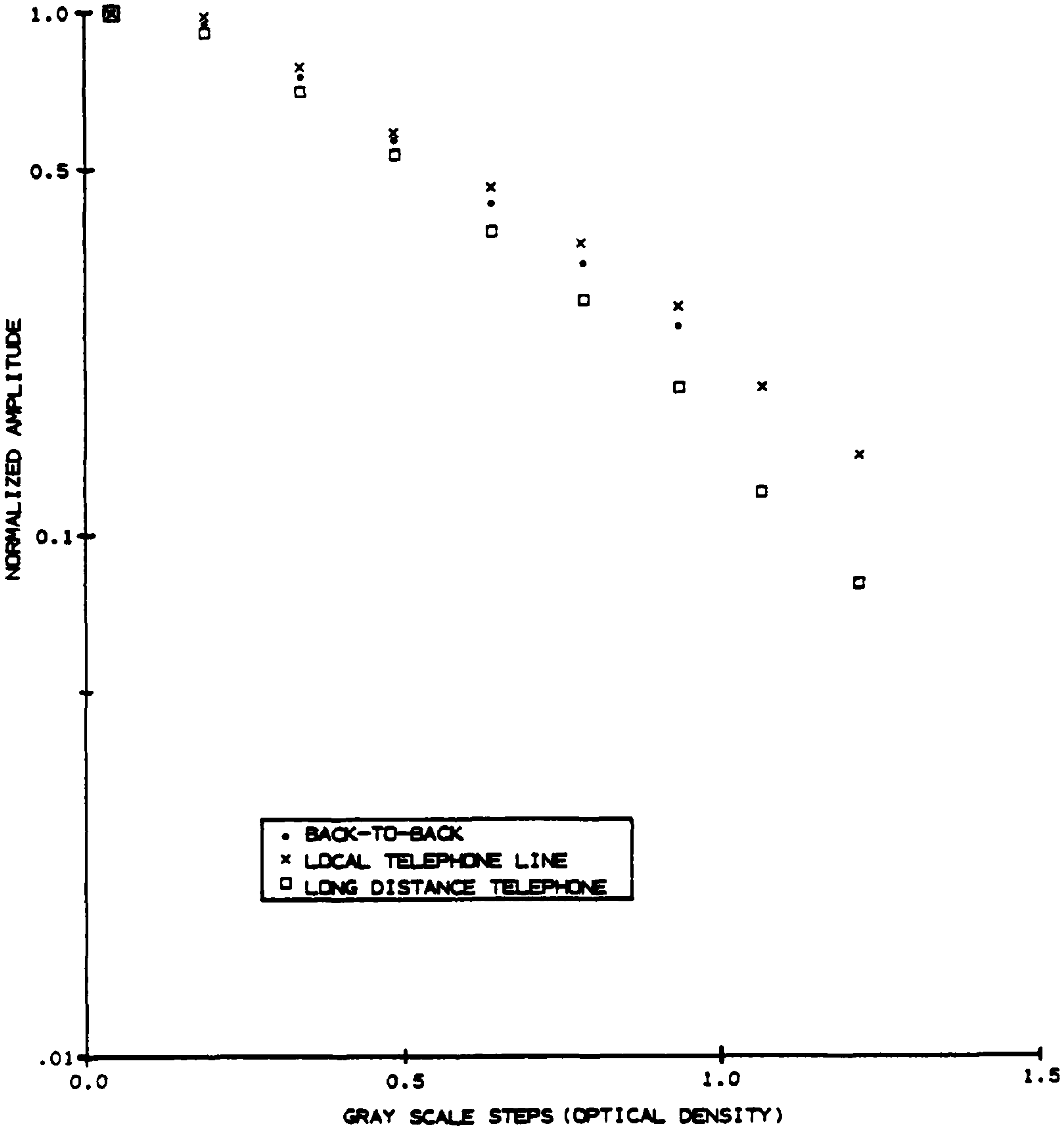


Figure 117. Gray scale response for digital video transmission, camera image.

Gray Scale (Optical Density)	Normalized Amplitude: Back-to-Back Camera	Local Telephone Camera	Local Telephone VDR	Long Distance Telephone Camera	Long Distance Telephone VDR
0.14	1.00	1.00	1.00	1.00	1.00
0.19	0.95	0.98	0.98	0.92	0.90
0.34	0.75	0.79	0.79	0.70	0.70
0.49	0.58	0.59	0.59	0.53	0.53
0.64	0.43	0.46	0.46	0.38	0.38
0.78	0.33	0.36	0.34	0.28	0.28
0.93	0.25	0.27	0.26	0.19	
1.07		0.19	0.19	0.12	
1.22		0.14	0.13	0.08	

Table 47. Gray scale response data for digital video transmission (GCM).

VDR - Video Disc Recorder

Gray Scale	Normalized Amplitude					
	Back-to-Back		Local Telephone		Long Distance Telephone	
(Optical Density)	Camera	VDR	Camera	VDR	Camera	VDR
0.04	1.00	1.00	1.00	1.00	1.00	1.00
0.19	0.93	0.94	0.96	0.96	0.97	0.96
0.34	0.76	0.79	0.80	0.80	0.81	0.81
0.49	0.60	0.64	0.63	0.63	0.63	0.64
0.64	0.47	0.49	0.50	0.48	0.50	0.39
0.78	0.36	0.38	0.39	0.38	0.39	0.36
0.93	0.28	0.29	0.30	0.28	0.30	0.38
1.07	0.20	0.22	0.22	0.21	0.21	0.20
1.22	0.15	0.16	0.15	0.14	0.14	0.13
1.36	0.09	0.11	0.10	0.10	0.10	0.07
1.51	0.04	0.07	0.06	0.07	0.06	0.04
1.65	0.02	0.05	0.04	0.04	0.03	

Table 48. Gray scale response data for digital video transmission (Cohu).

VDR - Video Disc Recorder

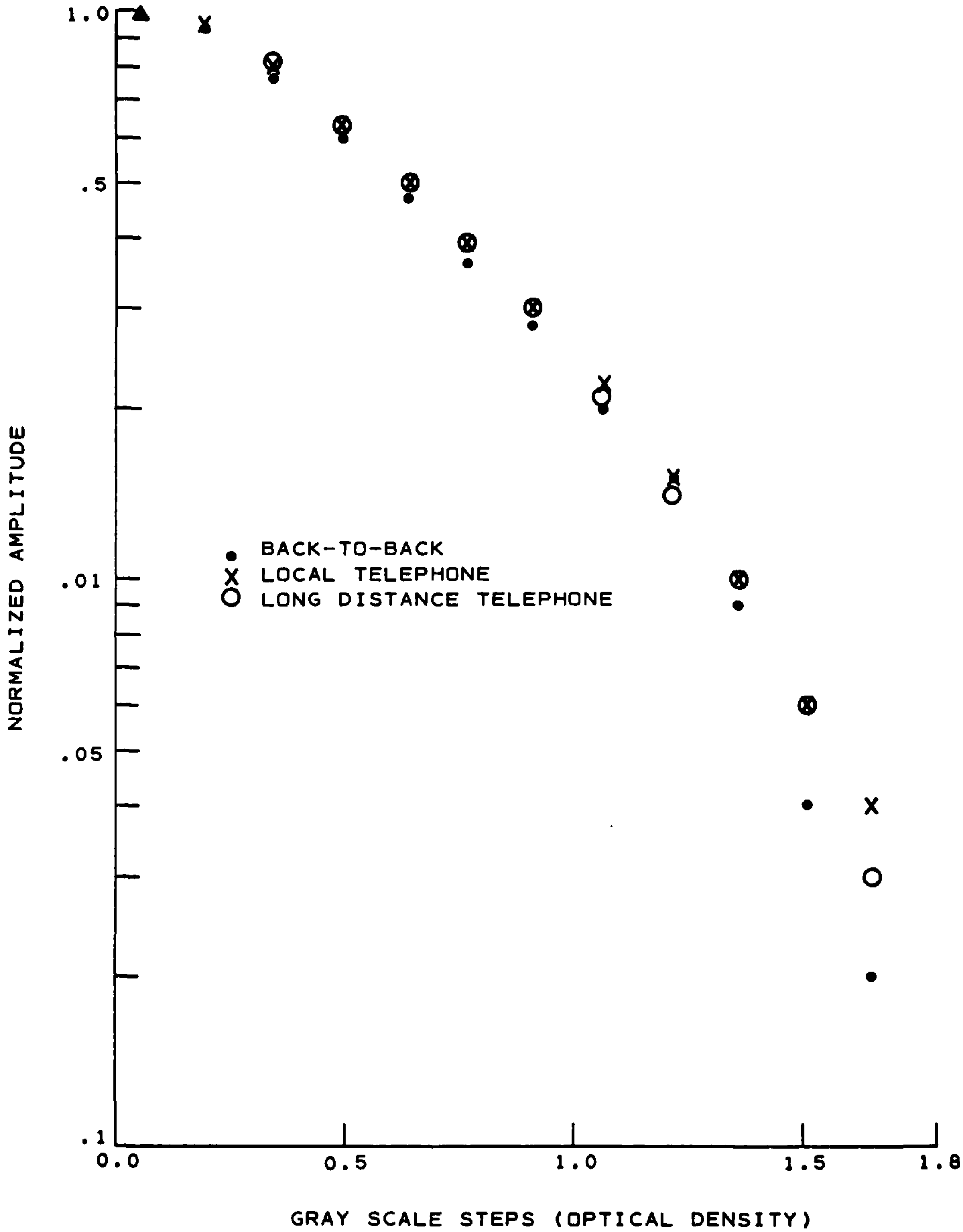


Figure 118. Gray scale response for digital video transmission, Cohu image.

The measurements obtained for the various conditions tested were essentially the same, as seen in table 48 and figure 118. The video disc recorder further demonstrated the ability to reproduce gray scale response similar to the camera image. Listed below are the number of gray levels observed on the TV monitor for the conditions tested.

	Number of Gray Levels	
Communication Link	Camera	Video Disc Recorder
Back-to-Back	12	12
Local Telephone	12	11
Long Distance Telephone	12	11

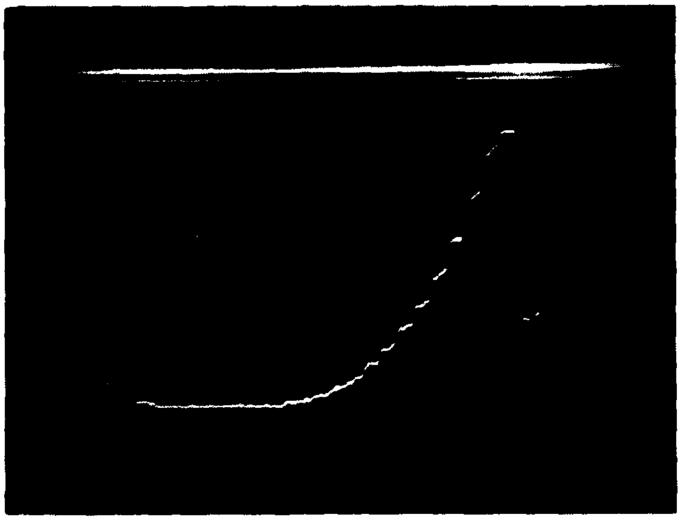
Figure 119 shows photographs of the oscilloscope display for the back-to-back and long distance telephone line communication links. A comparison of analog (figure 115) and digital (figure 119) transmission modes for long distance telephone lines shows a noticeable reduction in the amount of noise for the digital mode. This results in an increase in the number of distinguishable gray levels on both the oscilloscope display and TV monitor.

The digital mode gray scale response curves for the CGM (original testing) and Cohu (retesting) cameras are similar in shape, as indicated by figures 117 and 118, although the gray scale response curve for the Cohu camera extends farther than that for the CGM camera. Increases in gray scale response for the Cohu camera were due to the reduction in noise observed on the oscilloscope display. The reduction in noise may be attributed to 1) reduction in environmental ambient noise levels, 2) improvement in camera performance characteristics, or 3) a combination of these two factors.

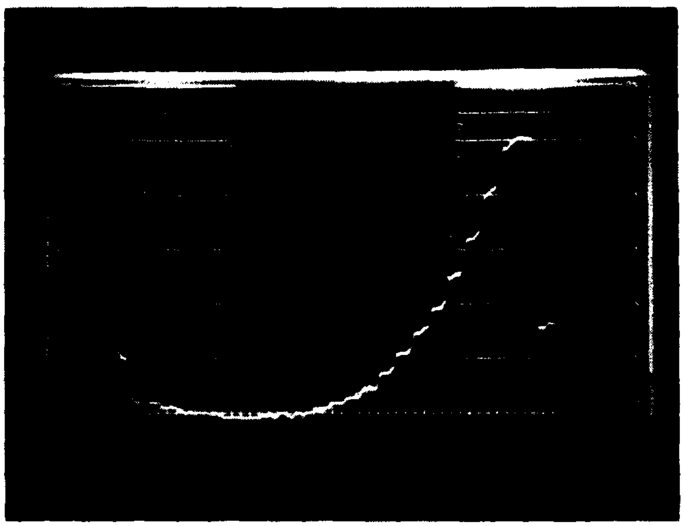
5.12 TAPE RECORDER PERFORMANCE

The audio tape recorder used to record and play back transmitted video information was not tested as part of the original laboratory tests, because of the tape recorder malfunction. Prior to commencing the system tests and while the tape recorder was operational, the RMDS terminals failed to reconstruct successfully the played-back tape-recorded video signals via incoming landline by using the Sanyo Model 4553 tape recorder furnished with the RMDS terminal. Reconstruction of played-back tape-recorded incoming landline video signals was successfully accomplished by means of a Hewlett-Packard 3960 instrumentation tape recorder system under laboratory conditions. The failure to reconstruct played-back tape-recorded incoming landline signals with the Sanyo tape recorder is attributed to the modem modulation scheme (Differential Phase Shift Keying - DPSK) used for transferring the data and the tape recorder reproduction qualities of harmonic distortion, tape speed stability, and signal-to-noise level in playback.

Harmonic distortion and tape speed instability, if too great, will each produce smearing of the spectral phase energy of the playback signal about the transmitted value. This will result in a reduction of the spectral phase energy transmitted through the bandwidth of the notch filter in the modem receiver. This causes a reduction in the effective SNR for the phase signal to be demodulated and produces significant bit error



(a) Back-to-back



(b) Long distance telephone

Figure 119. Gray scale photographs for digital transmission, Cohu camera.

rates in the demodulated signal. Extreme tape playback instability can produce variations in the frequency of the carrier signal, which will result in a loss of phase locking by the modem receiver.

Of the three forms of signal distortion listed above, DPSK is least sensitive to decrease in the SNR levels. DPSK modulation schemes are capable of a 1×10^{-5} bit error rate for 18 to 24 dB SNR conditions, although variation in SNR on the order of 3 dB can produce drastic changes in the bit error rate. Clearly, the reproduction quality of the tape recorder system must be improved if the RMDS design scheme is to work correctly.

SECTION 6

SUMMARY

6.1 GENERAL

Laboratory testing of the Remote Medical Diagnosis System (RMDS) Advanced Development Model (ADM) was conducted during April through September of 1978 and March through May of 1979 at NOSC, San Diego, by NOSC personnel. The objectives of the laboratory tests were to provide quantitative and qualitative data on the functional parameters of the RMDS terminals and components, to define design risks associated with the current approach to RMDS implementation, and to provide baseline data to support the follow-on procurement of the RMDS Engineering Development Model (EDM).

Qualitative and quantitative testing of electrocardiograph, stethoscope, and video image transfer modes of the RMDS ADM terminals was performed by using various communication links -- back-to-back, local and long distance telephone lines, hf, and uhf/satellite. Additional tests, involving the video image transfer mode, were completed for comparison of:

- analog versus digital transmission
- fine versus coarse resolution
- live versus video disc recorded image
- TV camera utilization

A summary of the RMDS general systems measurements is provided in tables 49 and 50 for the original testing period and the retesting, respectively; these tables appear at the end of section 6.5.

6.2 ELECTROCARDIOGRAPH MODE

The transmission/reception of live electrocardiograph (ECG) signals via back-to-back, local telephone, and long distance telephone lines appeared to be of sufficient quality for diagnostic purposes. The ECG signal, when played back from the audio tape recorder at the RMDS receiving terminal, was of noticeably lesser quality and possessed noise similar to wow and flutter. A comparison of the Sanyo and Panasonic tape recorders, performed during the laboratory retesting period, indicated better reproduction quality for the Panasonic recorder, with a noticeable reduction in the amount of noise observed on ECG strip charts. An attenuation of the signal was observed at the receiving terminal in the form of a 10-28% decrease in height of the received ECG signal peaks. A similar attenuation of received ECG signals was reported during tests conducted at Colorado Video, Inc. (CVI) in August 1977. However, this attenuation does not appear to decrease the utility of the received ECG signal for manual analysis to any appreciable degree.

The values for total harmonic distortion (THD) for the back-to-back, local telephone, and long distance telephone line communication links were very similar, averaging 3.7%. Measured values of THD for the three communication links are listed in tables 49 and 50. The levels of harmonic distortion for the three communication links tested do not degrade the utility of the received ECG signal for manual analysis to any appreciable degree. An increase in the levels of harmonic distortion was observed for tape recorder playback of ECG signals. Harmonic distortion generated by the Sanyo tape recorder (15.0 to 17.0%) would produce noticeable and unacceptable distortion levels for ECG signal reproduction. Harmonic distortion generated by the Panasonic tape recorder (6.0 to 8.0%) should not degrade the utility of the received ECG signal appreciably.

The results of ECG linearity testing at NOSC differed noticeably from testing at Colorado Video, Inc. The values obtained for nonlinearity were 10% during the original testing period and 12% during the retesting period; these are noticeably larger than the less than 5% obtained in the CVI tests. The range of voltages used and methods for determining linearity differed between CVI and NOSC testing, which may account for the discrepancy. Similar values of linearity are obtained for CVI and NOSC testing when comparing similar input voltage ranges (1.0 V peak-to-peak). Limiting ECG input signal amplitude to approximately 1.0 V peak-to-peak should reduce system nonlinearity to an acceptable level without limiting ECG utility.

During laboratory testing and retesting, ECG noise level measurements were complicated by high ambient levels of rf and 60 Hz noise that were found to exist at the NOSC facility. Listed below are the various types of noise identified:

Original Testing

- Random 1.5 - 2.0 V peak-to-peak noise spikes, of unknown origin
- 30-60 mV daily periodic 1 MHz communication signal with coding of 20 MHz, of unknown origin
- 10 mV random 60 Hz noise

Laboratory Retesting

- 17 mV peak-to-peak 5 kHz signal carrying a 100 MHz signal
- 2 V peak-to-peak 2 kHz square wave
- 0.6 V peak-to-peak 60 Hz sine wave

The questionable reliability of all noise measurements is due to the masking effect of the above noise signals. To obtain more accurate measurements, an rf shielded room is required. Measurements of ECG noise levels were made with a termination capacitor and load (to attenuate the noise mentioned above) and are listed in tables 49 and 50.

The general trend for noise levels was to increase as the complexity of the communication link increased, ie, from back-to-back to long distance telephone lines. During the laboratory retesting period, lower noise level measurements were obtained for the local and long distance telephone line communication links. The reduction in noise levels could be attributed to the period of time in which the testing took place (2 to 6 AM Sunday). With an RMDS ECG signal referenced to 1.0 V, the long distance telephone line communication link during the original testing period (highest noise level measurement at 50.0 mV) would represent only a 5% noise level, or signal-to-noise ratio of 26.0 dB. This indicated ECG signal transmissions mixed with typical telephone noise levels are not noticeably degraded. Receiver sensitivity testing was conducted in the ECG transmission mode. The RMDS receiving terminal continued to operate properly in the ECG mode until 1) the initial signal level had been attenuated by 12 dB and 2) 525 mV of white noise was added to the line signal. This indicated that the RMDS receiving terminal is sensitive enough for typical telephone line attenuation and noise levels.

6.3 STETHOSCOPE MODE

A qualitative review of the transmitted and received recordings of stethoscopic heart sound was not performed during these testing periods. Earlier testing of the stethoscopic mode had indicated that the quality of the transmitted recording was at the 85th percentile with respect to the LP record from which the tape was made, and that the quality of the received heart sounds was at the 40th percentile level. This indicated a 53% decrease in the quality of stethoscopic sound attributable to the RMDS terminals and communication links.

The frequency response of the stethoscope transmission mode should be more than adequate for heart lung sounds ranging from 15 to 1000 Hz. The frequency response curve showed a flat response between 4.0 and 100 Hz, and the 3 dB point for the higher frequency was estimated to lie at roughly 700 Hz. The results of this test correlate favorably with the CVI results.

Testing of phase response for the stethoscope mode indicated that phase shift was due to simple delay for back-to-back and long distance telephone line communication links. As expected, delay time increased with transmission distance, the delay time of the long distance telephone line being over 30 times that of back-to-back.

An increase in harmonic distortion was observed for increased communication link lengths (table 49). It should be noted that frequency dependent amplitude attenuation and delay distortion are typical of unconditioned telephone line transmission, with delay distortion increasing with distance. For the tests reported herein, this had the effect of distorting the spectral content of a transmitted signal nonuniformly, thereby resulting in increasingly worse harmonic distortion of the received signal over longer distances.

Measurement of stethoscopic noise levels was complicated by the same high level ambient rf noise observed during ECG noise testing mentioned above. Stethoscopic noise levels tended to increase with communication link complexity similar to ECG noise measurements (table 49) for the original testing period and showed an overall decrease for the retesting period (table 50). Noise level values obtained for the stethoscopic tape recorder playback were markedly higher then those for live reception (table 50). With an RMDS stethoscopic signal referenced to 1.0 V, the long distance telephone line communication link used during the original testing period (highest noise level measurement at 50 mV) would represent only 5% of the transmitted signal, or an SNR of 26.0 dB. This indicated stethoscopic signal transmission mixed with typical telephone noise levels was not noticeably degraded. The utility of tape-recorded playback is questionable, since noise levels of 100 mV (retesting, back-to-back) represent a 20.0 dB SNR when referenced to a 1.0 V signal.

6.4 VIDEO MODE

In general, the qualitative aspects of the images received were good, with only slight differences between conditions tested -- communication link, analog and digital transmission, fine and coarse resolution, and camera used. Quality of the images received tended to decrease slightly with respect to resolution and image detail as test conditions changed from 1) back-to-back to long distance telephone line communication link, 2) digital to analog, 3) fine to coarse resolution, and 4) uhf/satellite to hf. Images transmitted via the remote and Cohu camera were very similar to those transmitted via the CGM camera.

During testing (original test period) of the hf communication link, rf burst noise distorted image reception and retransmission of the image was required. Hf image transmission was also susceptible to interference from nearby hf frequencies. Rf burst noise was present during uhf/satellite communication link testing to a lesser degree, and occasionally noise in the form of vertical black and white lines would appear in the received image. It should be noted that uhf/satellite transmission and reception involved encryption/decryption of transmitted data. The necessity to retransmit images received via the uhf/satellite communication link was believed to be caused by the loss of crypto sync during transmission/reception.

Favorable results were obtained during horizontal resolution testing for both the CGM and Cohu TV camera/lens systems and the frame freeze (video disc recorder) system, with each near or surpassing specification. (See sections 5.3.1 and 5.3.2.) A decrease in horizontal resolution was observed for corner field response which is attributed to distortion at the edges of the lens system (section 5.3.1). Horizontal resolution for analog and digital transmission modes was noticeably affected by a 4 MHz ringing (sections 5.3.3 and 5.3.4). This ringing had its greatest effect beyond the 0.41 line pair per mm test pattern region, which corresponds to an approximate 2 MHz pattern signal. Horizontal resolution for the various conditions tested using analog and digital transmission modes ranged from 0.4 to 0.6 line pair per mm at the 50% modulation region.

The uniformity of light emitted over the surface of the viewbox was very poor. Luminance of the viewbox decreased noticeably in moving from the center, with an average decrease in luminance of 37% at the edges. The effect of poor lighting uniformity was seen in flatness of field testing. The observed decrease in signal level (section 5.5) for flatness of field tests can be directly attributed to the lack of a uniformly illuminated field. Testing of the TV camera/lens system indicated that geometric linearity is within 2%, which meets the specification requirement.

SNRs were measured for the CGM and Cohu TV camera/lens system, frame freeze system (video disc recorder), analog transmission, and digital transmission; these SNRs are listed in tables 49 and 50. A comparison of SNRs for the TV camera/lens system and video disc recorder showed a marked increase for the TV camera system as compared with a common bandwidth. This was expected, considering that the video disc recorder represents an additional source of noise. Two conditions that may account for this anomalous result are discussed at length in section 5.7.2. It should be noted that camera SNR values were larger than video disc recorder SNR values during tests using the RMDS terminal analog and digital transmission modes (tables 49 and 50). A marked increase in the SNR was seen for analog and digital transmission during the retesting period. A possible cause of the observed increase may be related to the time of day in which the testing took place. (See section 3.4, Laboratory Retesting.)

Equalization testing indicated that smearing or streaking of sharp black-to-white edge structures was minimal for all video systems tested (sections 5.8.1 through 5.8.4). However, ringing similar to that observed during horizontal resolution testing was present in analog and digital transmission modes. Testing of the video disc recorder time base stability indicated the presence of small amounts of jitter (1.6%) and drift (3.2%). Jitter and drift would manifest themselves as a smear, with decreased resolution in the horizontal direction.

The time required to transmit an image between RMDS terminals was measured by using a back-to-back communication link. Transmission times for analog and digital (2400, 4800, and 9600 bps) modes were measured while using coarse and fine resolution. The results of these tests are listed in table 49.

The CGM and Cohu TV camera/lens system and frame freeze (video recorder) were capable of producing 13 distinct shades of gray (sections 5.11.1 and 5.11.2). The addition of the communication link for analog and digital transmission resulted in a noticeable decrease in the number of distinct shades of gray observed. Distinguishable gray levels and dynamic range are a function of both the slope of the response curve and the SNR. The addition of the RMDS terminals and communication links resulted in a decrease in the SNR and therefore a decrease in the number of gray levels (sections 5.11.3 and 5.11.4). A marked increase in the number of distinguishable gray levels was observed for the analog and digital transmission when the Cohu TV camera was used. This increase may be attributed to 1) reduction in environmental ambient noise levels (increased SNR) and/or 2) improvement in camera performance characteristics. Improvement in SNR values for the retesting period indicated that a reduction in noise levels was the cause of the improved gray scale response. The response curves for the CGM and Cohu cameras were similar enough in shape to tentatively rule out a marked improvement in camera performance.

6.5 COMMUNICATION LINK

A comparison of the results obtained by using different communication links, ie, back-to-back, local telephone line, and long distance telephone line, showed a general trend of increased distortion with increase in communication complexity. A comparison of hf and uhf/satellite video transmission showed a noticeable decrease in noise interference for the uhf/satellite communication link. The uhf/satellite communication link was affected to a lesser degree by rf burst noise and channel frequency interference, although uhf/satellite transmission did occasionally experience image distortion due to loss of crypto sync.

- **ECG Transmission**

  - Harmonic Distortion

Communication Link	% Total Harmonic Distortion
Back-to-Back	4.0
Local Telephone Line	3.2
Long Distance Telephone Line	4.0

  - Linearity — 10% nonlinearity

  - Noise Level

Communication Link	RMS Noise Level (mV)
Back-to-Back	7.5
Local Telephone Line	30.0
Long Distance Telephone Line	50.0

- **Stethoscope Transmission**

  - Frequency Response — Roll-off at 100 Hz with -3 dB at 700 Hz

  - Phase Response

Communication Link	Time Delay (ms)
Back-to-Back	1.6
Long Distance Telephone Line	48.7

  - Harmonic Distortion

Communication Link	% Total Harmonic Distortion
Back-to-Back	3.0
Local Telephone Line	2.6
Long Distance Telephone Line	14.0

  - Noise Level

Communication Link	RMS Noise Level (mV)
Back-to-Back	7.5
Local Telephone Line	45.0
Long Distance Telephone Line	50.0

Table 49. RMDS general systems measurements for original laboratory testing.

- **Video Transmission**

  - Signal-to-Noise Ratio (SNR)

	SNR (dB)
TV Camera/Lens System	32.7
Video Disc Recorder	38.3

Analog Video Transmission

Communication Link	SNR (dB)
Back-to-Back	26.0
Local Telephone Line	30.9
Long Distance Telephone Line (average)	29.2

Digital Video Transmission

Communication Link	SNR (dB)
Back-to-Back	26.0
Local Telephone Line	26.0
Long Distance Telephone Line (average)	30.6

  - Video Transmission Time

Transmission Mode	Video Transmission Time (s) Coarse 256 x 256	Fine 525 x 256
Analog	34	78
2400 bps	179	366
4800 bps	97	196
9600 bps	51	111

  - Video Disc Recorder Time Base Stability

Jitter	1.6%
Drift	3.2%

  - Geometric Linearity (TV Camera/Lens System) — Within 2%

Table 49. RMDS general systems measurements for original laboratory testing (cont).

- **ECG Transmission**

  - Harmonic Distortion

Test Condition	% Total Harmonic Distortion
Back-to-Back (live)	3.4 to 5.2
Playback on Panasonic	6.0 to 8.0
Playback on Sanyo	15.0 to 17.0

  - Linearity

Voltage Range	Nonlinearity
+2.5 to -2.5	12%
0.0 to +1.0	3%
0.0 to -1.0	5%

  - Noise Level

	RMS Noise Levels (mV)	
Communication Link	Live	Tape Playback
Back-to-Back	6.0	6.5
Local Telephone Line	4.0	4.0
Long Distance Telephone Line	6.0	6.0

  - Receiver Sensitivity

Dynamic Range	12 dB
Noise Level Dropout Threshold	525 mV rms

- **Stethoscope Transmission**

  - Noise Level

	RMS Noise Level (mV)	
Communication Link	Live	Tape Playback
Back-to-Back	24	100
Local Telephone Line	13	90
Long Distance Telephone Line	12	140

Table 50. RMDS general systems measurements for laboratory retesting.

- Video Transmission

- Signal-to-Noise Ratio (SNR)

TV Camera	SNR (dB) Camera Only	SNR (dB) Camera + Filter (4 MHz)
CGM	31.9	38.2
Cohu	34.5	40.6

Frame Freeze	SNR (dB)
CGM Image	37.6
Cohu Image	34.0

- Analog Video Transmission

	SNR (dB)			
	Camera		Frame Freeze	
Communication Link	CGM	Cohu	CGM	Cohu
Back-to-Back	38.8	38.2	38.3	37.7
Local Telephone Line	38.7	38.1	37.3	37.6
Long Distance Telephone Line	35.6	37.1	35.2	35.9

- Digital Video Transmission

	SNR (dB)			
	Camera		Frame Freeze	
Communication Link	CGM	Cohu	CGM	Cohu
Back-to-Back	40.0	38.2	38.9	37.4
Local Telephone Line	39.2	38.7	38.8	38.2
Long Distance Telephone Line	37.7	38.2	36.8	36.8

Table 50. RMDS general systems measurements
for laboratory retesting (cont).

SECTION 7

CONCLUSIONS

The following conclusions were derived from RMDS laboratory testing:

1. In general, the RMDS ADM terminals operated satisfactorily and within specification during laboratory testing at NOSC. A summary of general systems measurements is given in tables 49 and 50, which list the technical performance parameters of various elements and operational modes of the ADM terminals.

2. Electrocardiograph signal transmission was of sufficient quality for diagnostic purposes, with the exception of the playback audio tape recorder.

3. A noticeable decrease was observed in the quality of stethoscopic heart sounds via analog transmission. This decrease is not felt to be tolerable for diagnostic purposes.

4. The quality of video image transmission was good, with only slight variations between analog, digital, coarse, and fine modes of operation. No noticeable improvements in RMDS video quality were obtained through the use of the Cohu TV camera. Better quality was obtained for the digital and fine modes versus analog and coarse modes of operation, but all video images were of sufficient quality for diagnostic purposes in most general cases.

5. The Sanyo Model RD 4553 audio tape recorder did not have sufficient quality to record/play back transmitted ECG, stethoscopic, and video information.

6. The lighting uniformity of the viewbox was very poor. This caused a significant decrease in flatness of field for video images of the TV camera and monitor.

7. The RMDS ADM terminals and/or test equipment used during testing were susceptible to the ambient levels of rf noise that existed at the NOSC facility. This may have been due to the high levels of rf signals at the NOSC facility or to a susceptibility of the RMDS ADM terminals to environmental electronic noise.

8. The 4 MHz ringing present during the horizontal resolution and equalization tests was determined to be generated from the internal clock circuits. The video bandwidth compressor sampling circuit had a 4 MHz cutoff filter, which could have caused the observed ringing if it were underdamped.

SECTION 8

RECOMMENDATIONS

The following recommendations are made as a result of laboratory testing for the procurement of future RMDS Engineering Development Models (EDMs):

1. To provide the best quality video images, only digital transmission should be considered.

2. To provide diagnostically acceptable quality for stethoscopic heart/lung sounds, a digital transmission mode should be used.

3. The video resolution of the system should be, at a minimum, 525 lines by 256 pixels, with 6 bits per pixel element (525 x 256 x 6); the preferred resolution for more detailed radiographs should be 525 x 512 x 8.

4. No audio tape recorder should be incorporated in the EDM terminals. The usefulness of an audio tape recorder has not been established, and its technical acceptability was not demonstrated.

5. A digital storage capability, compatible with video resolution (up to 525 x 512 x 8), ECG, and stethoscope requirements, should be provided.

6. The EDM terminals should incorporate a more uniform light source for use of video images, specifically in the lightbox for radiographs.

7. To protect the EDM terminals from the high levels of rf noise in the electronic environment aboard ship, the EDM terminals must be shielded or other design changes must be employed to reduce their susceptibility to rf noise interference.

8. The EDM terminals must be designed to eliminate electronic interference from internal circuits. The system should be designed with all circuits specified at a noise level at least 10 dB below the random noise level.

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